A STUDY OF THE GROWTH AND PHENOLOGICAL DEVELOPMENT OF FIFTEEN SPECIES OF PLANTS ON THE JORNADA EXPERIMENTAL RANGE DURING 1979 AND 1980

A Study of the Growth and Phenological Development of Fifteen Species of Plants on the Jornada Experimental Range During 1979 and 1980

by

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ABSTRACT

A knowledge of the phenological development of forage species can be very useful in the management of desert rangelands. During 1979 and 1980 observations and measurements were made at weekly intervals on 14 plant species, including annual forbs, perennial forbs, perennial grasses and shrubs. Growth curves of all species showed a very high correlation with summer precipitation and in most cases precipitation dictated the timing and magnitude of expression of reproductive phenophases. Regression analyses were used to examine the relationships between dimensional or volumetric measurements and plant biomass. Few good predictors of plant biomass were found. The wide variation in phenological expression and biomass accumulation among years prevents the use of any species specific factor for the adjustment of biomass determinations made prior to the peak standing crop.

INTRODUCTION

A recent definition of phenology was distilled by the U.S. International Biological Program Phenology Committee (Lieth, 1974):

> Phenology is the study of the timing of recurrent biological events, the causes of their timing with regard to biotic and abiotic forces, and the interrelation among phases of the same or different species.

The above definition includes, but is not limited to the classical approach dating from the days of Linnaeus (Hopp, 1974), wherein dates of bud opening, flowering, leaf fall, etc., were recorded and used to guide agricultural or other activities of man.

The phenological progression of plants has played an important role in the development of range management concepts such as range readiness, deferred grazing, etc. Biomass production rates (Taylor, 1974; Al-Mufti et al., 1977); nutrient transfer rates (Sosebee and Wiebe, 1973), and plant-water relationships (Blaisdell, 1958) are examples of processes associated with the phenology of plants. It has been suggested that major land management practices and productivity studies could be keyed to specific plants and selected phenological events (Caprio, 1966; Lieth and Radford, 1971). It has also been pointed out that plant indicators are cheaper than instruments (Hopp, 1974).

This study was initiated to explore the feasibility of, and, if possible, to meet the following objectives: (1) Objectively characterize the seasonal development of species by phenophases covering the spectrum of recurrent morphological development; (2) To determine threshold environmental triggers for phenophases of individual species so that predictive phenological models may be developed; (3) To relate phenological stage to biomass production so that the actual productivity of range sites may be estimated from single point-in-time samples (phenological adjustment factors); and (4) To determine the impact of grazing upon the phenological development of plants.

DESCRIPTION OF STUDY AREA

The study sites were located on the Jornada Experimental Range which is located 37 kilometers north of Las Cruces in south central New Mexico. The climate is typical of the semidesert grassland, the most arid of the North American grassland regions. Long-term precipitation records maintained on the Jornada Experimental Range show an average annual precipitation of 9.05 inches (230 mm). In winter, precipitation is derived from frontal storms originating over the Pacific Ocean. The low-intensity precipitation originating from the frontal storms normally covers wide areas and may last for several days. Summer precipitation originates in the Gulf of Mexico and occurs as intense, convective thunderstorms which are usually highly localized and of short duration. Fifty-two percent of the annual rainfall occurs between July 1 and September 30. Droughts, or periods of low rainfall that seriously injure vegetation, are a recurrent climatic phenomenon.

The average maximum temperature is highest in June when it averages 97° F (36° C); the temperature is lowest in January when the average maximum is 56° F (13.3° C). The average frost-free period extends from April 20 to October 27, or 190 days. The effective growing season is normally July through September when both precipitation and temperature are favorable for plant growth. Humidity is low and evaporation from a free water surface averages 92.4 inches (235 mm) per year.

The Jornada Experimental Range includes portions of the San Andres Mountains but the study sites used were all located on the level-to-gently undulating floor of the intermountain basin which constitutes the Jornada Plain. Elevation of the plain is about 4,200 feet (1,260 m). The basin is closed, with no external drainage, and water occasionally collects in the scattered

playas. Coarser sediments are found near the foothills, and finer soil particles, the silts and clays, are found in the lowest areas. The soils are characterized by a lack of organic matter, little change in texture between surface soil and subsoil, and a high lime content. Through time, the lime has been leached downward and deposited in a caliche layer, often indurated, at depths of a few inches to several feet.

Although often classed as semidesert grassland the Jornada Plain contains a complex of vegetation types ranging from pure stands of grass, through savanna types with grass interspersed by shrubs to nearly pure stands of shrubs. There has been an extensive invasion of former grassland areas by shrubs within the historical period. Dune formation and extensive erosion resulting from shrub invasion has profoundly altered the original soils and vegetation types.

DESCRIPTION OF PHENOLOGICAL OSERVATION STUDY SITES

To accomodate the plant species selected for phenological studies it was necessary to establish four study sites (Figure 1). For convenience, these will be designated as Sites A, B, C, and D. Particulars for each site are given below:

Site A

Plant species studied. Plant nomenclature follows Correll and Johnston (1970).

Honey mesquite (*Prosopis glandulosa*)	Shrub
Mesa dropseed (*Sporobolus flexuosus*)	Perennial grass
Two-leaf senna (*Cassia bauhinoides*)	Perennial Forb
Broom snakeweed (*Xanthocephalum sarothrae*)	Half-shrub
Fluffgrass (*Erioneuron pulchellum*)	Perennial grass

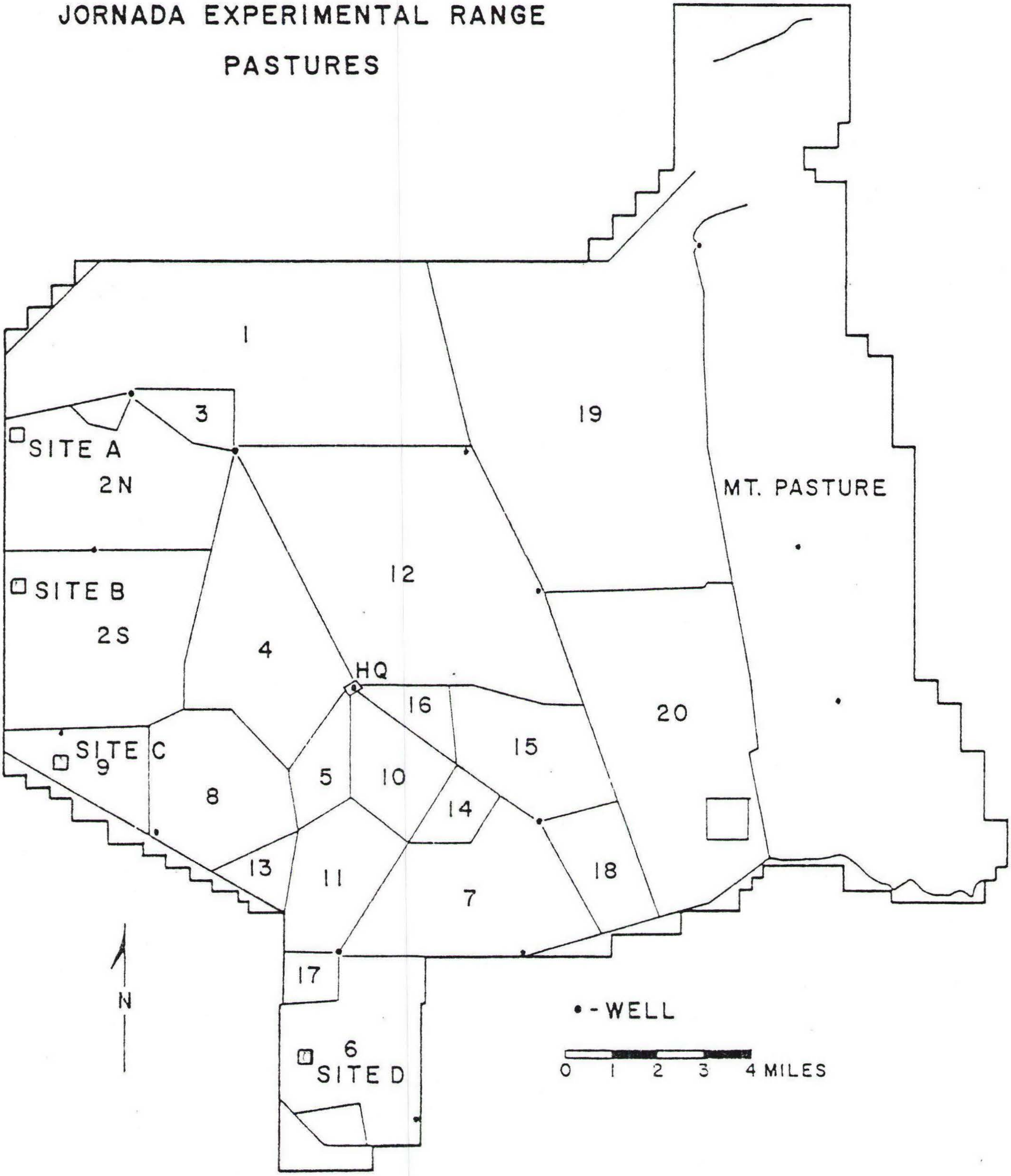

Figure 1. Map of the Jornada Experimental Range showing the location of phenology study sites A, B, C, and D.

Soil type

Onite sandy loam

Range type

Sandy

General description

An area of mesquite duneland with dunes occupying about 25 percent of the surface area.

Site B

Plant species studied

Mesa dropseed (*Sporobolus flexuosus*)	Perennial grass
Spike dropseed (*Sporobolus contractus*)	Perennial grass
Big globemallow (*Sphaeralcea incana*)	Perennial forb
Desert baileya (*Baileya multiradiata*)	Annual forb (sometimes a weak perennial)
Wislizenus spectaclepod (*Dithyrea wislizenii*)	Annual forb (can function as biennial or perennial)
Purple rollleaf (*Nama hispidum*)	Annual forb

Soil type

Onite loamy sand

Range Site

Sandy

General description

An area of mesquite duneland with dunes occupying about 25 percent of the surface area. Differs from Site A only in that the area was sprayed with 2,4,5-T for mesquite control in 1976 and 1977.

Site C

Species studied

Black grama (*Bouteloua eriopoda*) Perennial grass

Plains bristlegrass (*Setaria macrostachya*) Perennial grass

Soil type

Simona

Range site

Shallow sandy

General description

A nearly level area where an excellent stand of black grama has persisted. Invading mesquite has been kept at low levels by treatment of individual plants with herbicides.

Site D

Species studied

Tobosa (*Hilaria mutica*) Perennial grass

Bush muhly (*Muhlenbergia porteri*) Perennial grass

Soil type

A complex including Berino, Dona Ana, Onite (gravelly variant), Tres Hermanos, Nickel, and Canutio soils (Gile and Grossman, 1979; Soil Conservation Service, 1980)

Range Site

Local area of study site tentatively classed as a loamy range site although gradations to sandy and gravelly occur.

General description

A gently sloping area near the foot of a piedmont slope where creosotebush (*Larrea tridentata*) has invaded an area formerly dominated by black grama. The study site was located on a

16 ha tract sprayed in 1971 and 1972 for creosotebush control. The effective treatment resulted in the development of an excellent stand of bush muhly. Tobosa also occurs and while the site is not representative of typical tobosa areas the joint occurrence of the two species eliminated the need for a fifth study area.

METHODS AND PROCEDURES

To provide protection from livestock each study site was located within an existing exclosure, or as in the case of Site D, an exclosure was constructed. Minimum size of the exclosures was approximately one acre.

For species with relatively high densities, individuals were selected for observation by locating a 30 m base line within a stand and then drawing random coordinates from an area 30 x 10 m. Individuals closest to 20 random points were marked with a numbered stake. This method of plant selection was used for desert baileya and all grasses. Spectaclepod typically grows on mesquite sand-dunes. On a randomly selected dune five individuals were marked in each of the north, west, south and east quadrants of the dune. For species with relatively low densities, e.g., big globemallow, purple rollleaf, and broom snakeweed, a starting point was randomly drawn and all individuals encountered in a 5 m wide strip were marked until the requisite 20 individuals were marked.

Ten mesquite dunes were selected and five individual branches, uniformly distributed around the periphery of the dune, were tagged for observation. Where the dunes had an open side and top the fifth observation point was put on top of the dune. Ten accessible saltbush plants were selected and 5 twigs on each bush were marked for observation.

The procedures followed in recording phenological observations were adapted from those recommended by West and Wein (1971). To reduce the variability

inevitably encountered on large multi-stemmed individuals, observations were confined to a single morphological entity. On each of the grass plants selected for observation (fluffgrass excepted) an individual culm was marked by colored electrical wire. Branchlets on broom snakeweed were marked similarly. Numbered tags were used to mark individual twigs on saltbush plants and single branches on mesquite plants. Annual and perennial forbs and fluff grass were observed as entire individuals.

Each phenological event, e.g., bud swelling and opening, leaf emergence, flowering, etc., was rated on a scale of 0 to 1. For example, the first swelling of buds on a mesquite branch would rate a score of 0.1. The score progressively advanced until the buds burst and rated a score of 1. Such a rating is, of course, subjective and requires considerable knowledge of the normal course of the development of the plants. The rating system does attach a numerical score to readily observable phenological events and permits the calculation of an average condition for the plants under observation. Emergence of individual grass leaves was also rated on a scale of 0 to 1. For example, if the first leaf was fully emerged it would have a score of 1, a half-emerged second leaf would rate a score of 0.5, and if the tip of the third leaf was visible it would be scored as 0.1. The numerial leaf number for the culm would be 1.6. Change in each observed variable was determined by subtracting the initial datum from the final datum of any one interval (week).

Numerically scored events are adequate for description of phenological events through time. However, they are not suitable for indices of increases in biomass which are necessary if the objective of deriving phenological adjustment factors (PAF) is to be met. Easily obtained measurements related to mass or volume increase such as culm and twig length for grasses and shrubs, and height and diameter for forbs were taken. This approach has been termed

dimensional analysis (Newbould, 1967; Whittaker, 1965, 1966). Regression analyses were used to obtain the relationships of plant biomass to measured attributes. Twig and culm measurements were also useful in delineating periods of active growth.

All of the species selected for study were observed during 1979. In 1980 only perennials were available for observation since practically no spectacle pod, desert baileya or purple rollleaf plants appeared.

Data acquisition systems were installed at sites A and B. These systems scanned sensors at 5-minute intervals and recorded hourly averages of environmental parameters on magnetic tape. Parameters measured included total and net radiation at a height of 1.5 m, wind velocities at heights of 0.5, 1.5 and 3.0 m, wind direction at 3 m, air temperatures at 20 cm and 1.2 m (approximate height of standard Weather Bureau instrument shelter), soil temperatures at 5, 10, 25 and 40 cm depths, soil water at depths of 10, 25 and 40 cm (gypsum block sensors), soil temperatures at 5 cm depth on north, west, south and east dune exposures. Equipment failures precluded the collection of continuous records at both sites. A fairly continuous record was acquired at Site B in 1979 and at Site A in 1980. These data are being transferred to the University of New Mexico computer and will not be available for analysis for several months.

A recording, weighing-type raingauge was installed at each study site. A hygrothermograph was installed in a standard instrument shelter at Sites B, C, and D. Only temperature data were obtained from the hygrothermographs since it was found that the hair sensors for humidity had such a short life span that replacement was impractical.

Large numbers of plants were harvested at the end of the 1979 growing season to determine biomass. Height and basal area were recorded for grasses, and height and diameter for forbs. All clipped samples were hand-separated

into old dead, old live and current live components, and oven-dry (60° C) weights determined. In 1979 a clipping experiment was conducted on mesa dropseed. One hundred individual plants were clipped at ground level, 100 plants at a height of 10 cm and 100 plants served as a control treatment. The plants were clipped on April 30 and growth of the plants recorded at intervals during the remainder of the season. After growth terminated all plants were clipped at ground level and oven-dry weight determined. In 1980 another clipping experiment was carried out on mesa dropseed. Clipping heights were 5, 10 and 15 cm. However, rodent damage was so extensive that nothing could be salvaged from the experiment. A clipping study of black grama fared better. Twenty-five black grama plants were clipped on June 24, 1980 and observations made for the remainder of the season. The clipped plants and 25 control plants were harvested at the end of the season and oven-dry weights determined. Plants of tobosa and bush muhly were also clipped in 1980. As with mesa dropseed, extensive rodent grazing and dry weather made the effort futile. The population of plains bristlegrass available for study was so small that there were not enough plants for a clipping study in either 1979 or 1980. The same was true for spike dropseed.

An attempt was made in 1980 to determine what relation existed between height and leaf number of grass culms and individual culm weights. Individual culms were separated from grass plants, yielding a morphologically entire unit. Separation of an entire culm eliminated the variability imposed when culms are clipped at ground level. "Ground level" and distance to the base of a culm varies widely between grass plants. Beginning on March 20 collections of 100 culms of mesa dropseed, spike dropseed, black grama, fluffgrass, tobosa, bush muhly and plains bristlegrass were made. The number of collections varied from three to five for each species. The final collection was of mature culms with

seed heads exerted. Height, leaf number and oven-dry weight were determined for each culm.

It was originally intended to place all data in computer files. Personnel turnovers and computer breakdowns made this impossible. Consequently, all field sheet summations were performed by hand. The Statistical Analysis System (SAS) available on the New Mexico State University computer was used to perform part of the correlation and regression analyses. Computer facilities were also employed in constructing graphs.

RESULTS AND DISCUSSION

Precipitation Patterns

Before the presentation of phenological observations, we will present the precipitation patterns at the study sites. Not unexpectedly, precipitation had a profound influence on the timing and magnitude of phenological events. At study sites A, B and C rainfall records were available for a period prior to the study so the rainfall for the entire crop year (12 months preceeding the end of the growing season) in which the study began has been included in (Table I). At study site D precipitation records are available only for the period of study, May, 1979 to November, 1980.

The most striking feature of the precipitation pattern is the far above normal precipitation during the fall of 1978. This precipitation, along with better than average precipitation during the winter months, resulted in dense stands of annual plants during the spring and summer of 1979. In contrast, the total lack of precipitation in October and November of 1979 and the relatively low winter and early spring precipitation resulted in a nearly complete absence of annual plants during the spring and summer of 1980.

At first inspection, differences between sites do not appear large (Table II and III). However, the differences were large enough in amount and precipitation events differed enough in timing among sites to affect the development of plants. These among-site differences will be discussed with reference to particular species.

Each species observed will be presented separately to preserve clarity. To avoid the repetition of calendar dates the phenological observations are denoted by number of elapsed weeks, starting with the first full week in March for 1979 and 1980. Observations were made for 39 weeks, terminating on December 1 in 1979 and on November 29 in 1980. In 1979 the first growth of most species began in the latter part of February. In 1980 many plants did not start growth until early March.

Table I. Monthly precipitation in mm at the phenological study sites and the long-term average for months of year.

Year	Month	Site A	Site B	Site C	Site D	Long-term average for month of year 1/
1978	Oct	81.5	69.9	79.5		24.1
	Nov	30.5	29.7	25.4		10.9
	Dec	23.4	10.2	4.8		14.0
1979	Jan	15.8	26.2	25.9		11.4
	Feb	13.7	5.1	6.9		9.7
	Mar	4.8	0	0		7.4
	Apr	14.2	12.7	5.8	2/	4.8
	May	20.3	17.8	10.9	20.1	9.1
	Jun	13.0	6.4	5.3	21.8	12.5
	Jul	56.4	60.7	21.3	24.6	44.7
	Aug	71.4	45.5	45.7	69.9	45.2
	Sep	26.4	22.1	20.1	10.9	36.1
	Oct	0	0	0	0	24.1
	Nov	0	0	0	0	10.9
	Dec	8.6	19.1	20.3	22.1	14.0
1980	Jan	9.7	19.3	23.1	29.0	11.4
	Feb	21.3	21.3	9.9	16.5	9.7
	Mar	1.5	.8	1.3	1.8	7.4
	Apr	8.9	11.9	7.9	10.7	4.8
	May	27.7	31.2	29.2	25.7	9.1
	Jun	.5	2.8	.3	0	12.5
	Jul	19.8	1.3	30.1	11.4	44.7
	Aug	21.1	23.6	17.0	29.0	45.2
	Sep	45.0	33.8	48.0	29.0	36.1
	Oct	16.5	22.9	20.3	11.2	24.1

1/ Based on 1915-1979 records from Jornada Experimental Range Headquarters.

2/ Rainguage installed.

Table II. Weekly precipitation in mm at phenological observation sites A and B with week 1 being the first full week in March each year. The number of precipitation events (rainstorms) contributing to each weekly total are shown.

	Site A				Site B			
	1979		1980		1979		1980	
Week	mm	No. of events	mm	No. of events	mm	No. of events	mm	No. of events
1								
2	4.8	1	1.5	1			.8	1
3								
4								
5								
6			8.9	1				
7					12.7	1		
8	14.2	1					11.9	2
9			27.7	9			31.2	2
10								
11	5.6	1			2.8	1		
12	14.7	3			15.0	3		
13	6.6	1			5.1	1		
14	6.4	3			1.3	2		
15								
16			.5	1			1.3	1
17							.8	1
18	5.8	2			7.4	3	.8	1
19	.8	1	8.1	1	1.8	1	1.0	2
20	43.2	5	2.5	1	47.5	6		
21	2.8	2	4.8	1	2.8	1	.3	1
22	3.8	1	4.3	1	1.3	1		
23	3.1	1	7.6	1	2.8	1	9.7	3
24	67.8	7	4.1	2	43.7	5	14.0	5
25			2.3	2				
26	.5	1	6.6	3				
27	5.1	2	3.3	1				
28	19.6	2	30.0	6	17.0	2	11.7	4
29	1.8	1			5.1	1	15.2	1
30			11.7	3			6.9	2
31								
32								
33			1.0	2			5.1	2
34			5.8	1			7.6	1
35			9.7	2			10.2	2
36			1/				1/	
37								
38								
39								

1/ Precipitation shown only to end of October.

Table III. Weekly precipitation in mm at phenological observation sites C and D with week 1 being the first full week in March each year. The number of precipitation events (rainstorms) contributing to each weekly total are shown.

	Site C				Site D			
	1979		1980		1979		1980	
Week	mm	No. of events	mm	No. of events	mm	No. of events	mm	No. of events
1								
2			1.3	1			1.8	1
3								
4								
5								
6			7.9	3			10.7	1
7	5.8	1						
8					1/			
9			29.2	2	2.3	1	25.7	2
10					.5	1		
11	1.5	1			5.1	1		
12	9.4	3			11.7	3		
13	4.6	1			2.5	2		
14					19.7	2		
15								
16			.3	1				
17	.8	1						
18	2.5	2			1.8	1		
19	.3	1	11.4	1			2.3	3
20	9.7	3	2.3	1	22.7	2	5.6	2
21	8.9	1	6.4	2			3.6	1
22			18.5	1				
23	6.1	1	3.8	1	9.4	1	.5	1
24	38.9	5	11.2	3	60.5	4	17.3	1
25			.5	1			1.0 2/	
26	.8	1	1.5	1			10.2 2/	
27								
28	17.5	2	41.2	7	10.9	2	14.0	1
29	2.5	1					3.8	1
30			6.9	2			12.2	5
31								
32								
33			4.3	1				
34			6.9	1			5.1	1
35			9.1	2			6.1	1
36			3/				3/	
37								
38								
39								

1/ Records for first 7 weeks not available.
2/ Raingauge malfunction. Values estimated from next nearest raingauge.
3/ Precipitation shown only to end of October.

Desert Baileya (<u>Baileya multiradiata</u>)

When the desert baileya plants were first examined on March 22, 1979 (3rd week) they were in a diminutive rosette stage. The rosettes were composed of leaves originating at about ground level and the average diameter of the rosettes was only 4.5 cm. While the rosettes increased steadily in diameter, stem elongation proceeded more slowly and the central stems did not reach measurable heights until the sixth week (Fig. 2). Diameter increment and height increment continued at a fairly constant rate until week 14 and 15, respectively, when the rates increased rather sharply (Fig. 2 and 3). This increase in growth rate was probably a response to 20 mm of precipitation received in weeks 12 and 13. In week 20 47.5 mm of precipitation were received. Both height and diameter increments increased sharply in weeks 21 and 22 (Fig. 1 and 2) and continued at relatively high rates until week 26. At this point in time diameter ceased to increase although height continued to increase slightly until week 29. Branching of the stem followed a pattern similar to that of height and diameter.

Flower buds began to appear during week 11 and blooming began during week 15. The plants bloomed profusely and the greatest increment in flowering occured in week 25. Some blooming continued until week 32 and seed development was not finished on all plants until week 35. At this time only a few individuals were still alive and they dried rapidly. Under the favorable moisture conditions prevailing in 1979 the reproductive phase of desert baileya far exceeded the vegetative growth stage in length.

On March 27 (8th week) 20 desert baileya plants were clipped to ground level and weights determined. At this time the average height of the plants was 3.3 cm. Weight per individual ranged from .01 g to .09 g with a mean of .05 g. Linear regression analysis indicated that height, diameter and volume

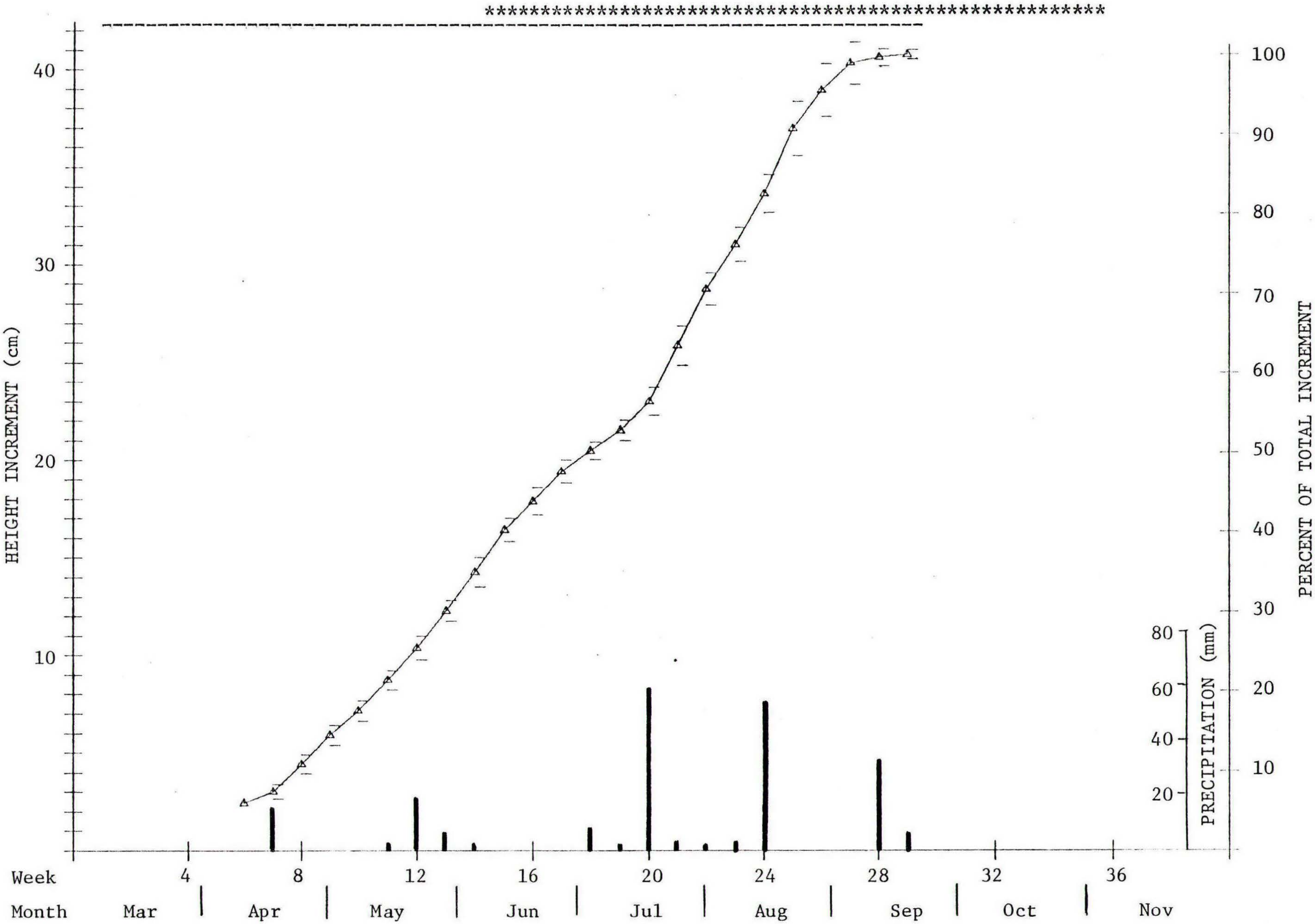

Figure 2. Accumulated weekly height increments for desert baileya at site B in 1979. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

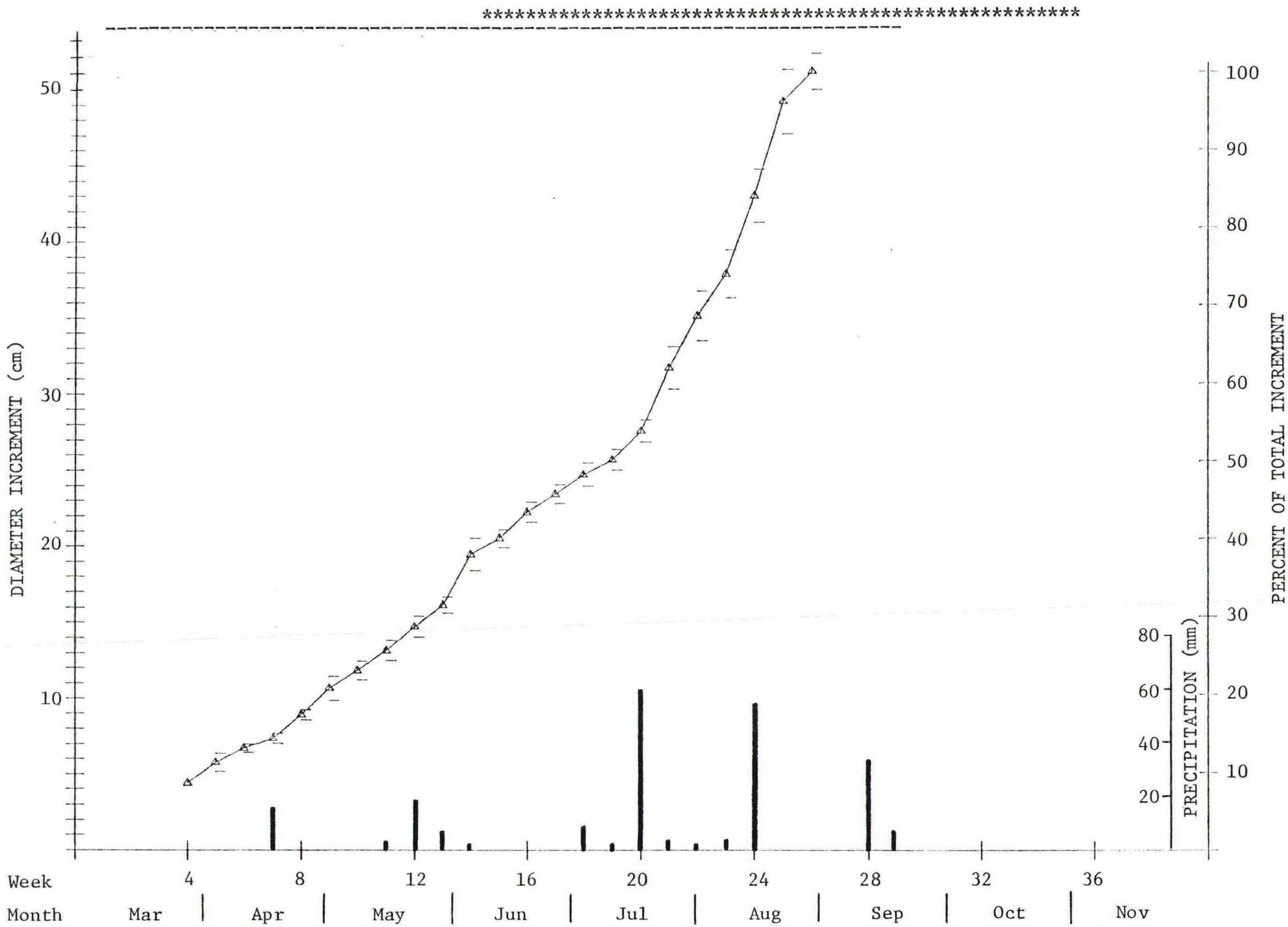

Figure 3. Accumulated weekly diameter increments for desert baileya at site B in 1979. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

(calculated as the volume of a cylinder $\pi r^2 \times$ height) would account for only 48, 24, and 31 percent, respectively, of the variability in weight of the individual plants.

On August 20 (week 25), when desert baileya was in full bloom and judged to be at or near maximum growth, 100 plants were collected and weight per individual determined. As can be seen in Figure 2 and 3 the collection was made 1 week too soon to measure maximum biomass. All plants encountered in a 1 m wide belt transect were clipped until 100 plants were obtained.

Mean weight of plants was 10.6 g, mean height 32.7 cm and mean diameter 38.5 cm. Regression analysis showed that height, diameter and cylinder volume would account for 32, 58 and 65 %, respectively, of the variability in weight. The large range in weight of individuals, 0.6 g to 55 g, indicates the magnitude of the problem associated with finding highly correlated parameters for a dimensional analysis and the necessity for extremely large samples.

Based on mean weight of individual plants the 8th week collection represents only .4% of the weight of individuals at the 25th week. If one were to use the graph of accumulated diameter increments to arrive at a PAF a sample taken in the 8th week (diameter 8.9 cm) would represent 17.8 % of the diameter of 50 cm attained by the 25th week. An upward adjustment of weight based on diameter would indicate the PAF should be the reciprocal of .178, or 5.618. However, the diameter-based PAF multiplied times the average weight of individuals harvested in the 8th week, 5.618 X .05 g, would indicate that plants in the 25th week should weigh .28 g, a value which is short of the mark by 10.3 g, or 97%. If volume, which showed the highest correlation with weight, is used to calculate a PAF, the results are closer to reality but not exactly encouraging. The 8th week volume is .38 % of the 25th week volume. The reciprocal of .0038 is 263.16 and 263.16 X .05 g = 13.2 g. Thus, adjustment of the 8th week

weight by a volume-based PAF overestimates the actual 25th week weight by 28%. As an item of interest the stand of desert baileya sampled in week 25 had a standing crop equivalent to 472 kg/ha.

Wislizenus Spectaclepod (Dithyrea Wislizenii)

The first examination of Wislizenus spectaclepod was made in week 4 on March 29, 1979. At this time stem elongation was well under way and the plants had an average height of 11.1 cm. Both buds and flowers were already present on the largest individuals. Growth in height continued at a rapid rate until week 9 and then slowed (Figure 4). The plants bloomed profusely during weeks 8 through 11. Fruit development started in the 7th week and was complete by the 15th week.

The population of Wislizenus spectaclepod, which could have been judged mature and dying after the 14th week, was completely revitalized by a single rainfall event. The 47.5 mm rainfall event of July 17th (20th week) triggered another spurt of growth and flowering activity. In the 21st week the average height increment was 5.8 cm and height growth continued at a lower rate until the 25th week. In some cases the terminal racemes of the central stem produced more buds and flowers. More frequently, lateral branches developed racemes, making the second crop of fruit nearly as large as the first. Flowering continued until week 30 and fruit development was finished in week 31. The plants dried and died very rapidly thereafter.

On April 27 (8th week) 20 Wislizenus spectaclepod plants were clipped and weighed. Average height, diameter and weight were 6.2 cm, 3.0 cm and 0.14 g, respectively. Using weight as the dependent variable, linear regression analyses yielded R^2 values of .68, .20 and .63 when height, diameter and volume (cylinder), respectively, were considered as the independent variable. Thus, height accounted for more of the variability in weight than either diameter or volume at this early stage of growth.

On May 22 (12th week) when the plants appeared to be at maximum development (subsequent rainfall and its effect could not be anticipated) all of the Wislizenus spectaclepod plants occurring on a dune where herbicide had killed

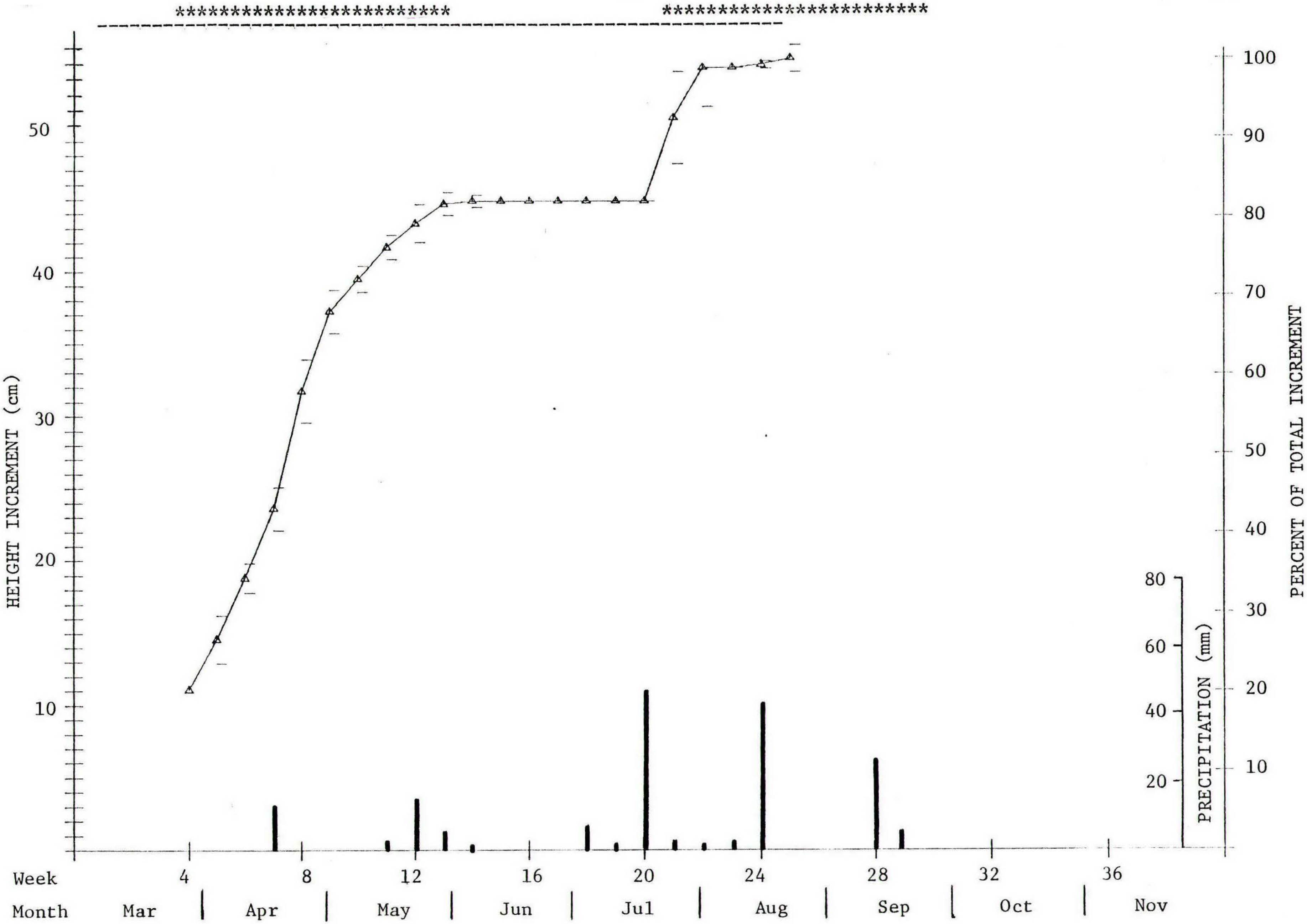

Figure 4. Accumulated weekly height increments for Wislizenus spectaclepod at site B in 1979. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

the mesquite were harvested. This population consisted of 220 individuals ranging in height from 7 to 87 cm with only 11 plants not in the flowering stage. Weight of individuals ranged from 0.07 g to 69.2 g ($\bar{x}$ = 10.6 g). The number of branches was determined as the plants were clipped and linear regression analysis showed that branches accounted for 80 percent of the variability in weight. Height of plant accounted for only 33 percent of the variability in weight. Considering only the surface area harvested (26.4 m^2), wislizenus spectaclepod had a standing crop equivalent to 884 kg/ha.

One might think that a sample size of 220 individuals would yield a statistically adequate sample for weight of individuals. Using Stein's procedure (Steel and Torrie, 1960), to sample a similar population for mean weight of individuals $\pm$ 5% with 95% confidence would require 2,825 individuals. A third harvest of spectaclepod was made on August 20 (25th week) when the second growth period was over. Since it was known that it was nearly physically impossible to obtain a truly adequate sample, 15 of the largest individuals available were subjectivly selected and harvested. If any valid PAF's are to be developed they must take into account the upper potential weight that may be attained. The 15 large plants ranged in height from 55 to 85 cm ($\bar{x}$ = 71 cm) and the weight range was from 135 to 470 g ($\bar{x}$ = 310 g). Linear regression showed that, for individuals of this size, height could account for none of the variability in weight, diameter could account for 36% of the variability in weight and cylinder volume only 21% of the variability in weight. With this size of individual, it was impractical to count the number of branches because there were so many branch subdivisions.

Height growth at week 8 was 73.2% of the height reached by week 12. Using the reciprocal of .732 as a PAF gives an adjustment factor of 1.366. Taking

1.366 x the 8th week weight (0.14 g) would yield a predicted weight of 0.19 g per individual for the 12th week. Since 0.19 g is only 1.8% of 10.6 g (12th week weight) the adjustment is in error by 98.2%. Assuming that precipitation had been sufficient to permit nearly all individuals to attain the size of the large plants harvested during the 25th week, another attempt at deriving a PAF can be made. Mean height at 8 weeks (32 cm) is 45% of the mean height of the large individuals at 25 weeks. The PAF equals the reciprocal of .45, or 2.222. Adjusting the 8th week weight (2.222 x 0.14 g) gives 0.31 g as a predicted weight for individuals in week 25 vs. the actual weight of 310 g per individual plant. Obviously height cannot be used as a parameter upon which a PAF for Wislizenus spectaclepod may be based. It is very doubtful if there is any easily measureable plant attribute which will have a high enough correlation with weight to serve as a basis for a PAF for this species.

Purple Rollleaf (Nama hispidum)

Observations began for purple rollleaf on March 29, 1979 (4th week). At this time the plants were small, ground-hugging rosettes with no discernable stem development. Since the plants did not reach measureable heights until the 8th week (mean height = 0.9 cm) the increase in diameter has been portrayed in Fig. 5. Starting from a mean diameter of 4.5 cm in week 4, the rosettes grew slowly until week 7. The 8th week increment in diameter was 3.2 cm. Thereafter diameter expansion and growth in height progressively decreased and had virtually ceased by the 16th week (June 21). No diameter or height increases were detected after the 21st week when mean diameter was 19.7 cm and mean height 13.8 cm.

Flower bud development was difficult to detect on the diminitive plants. Bud development and flowering were detected simultaneously beginning in the 5th week. Prolific flowering continued from the 8th through the 13th week. All plants had ceased to bloom by the 18th week (July 5). The rainfall event on July 17 caused blooming to resume in 7 of the 20 plants observed. The others matured fruit and slowly dried. Three of the 7 plants which resumed blooming continued to bloom until the 31st week (November 4). All plants were either dead or nearly so by the 32nd week.

On April 27 (week 4) 19 purple rollleaf plants were harvested and weighed. Mean diameter, height and weight were 2.6 cm, 1.7 cm and 0.03 g, respectively. Linear regression analyses yielded an R^2 value of .66 for diameter, .36 for height and .80 for cylinder volume, when weight was the dependent variable. In the 16th week (June 18) 50 purple rollleaf plants were harvested and weighed. Average height, diameter and weight were 7.0 cm, 10.4 cm and 0.94 g, respectively. The results of linear regression indicated that cylinder volume, diameter and height would acount for 88, 81 and 60 percent of the variability in weight, respectively.

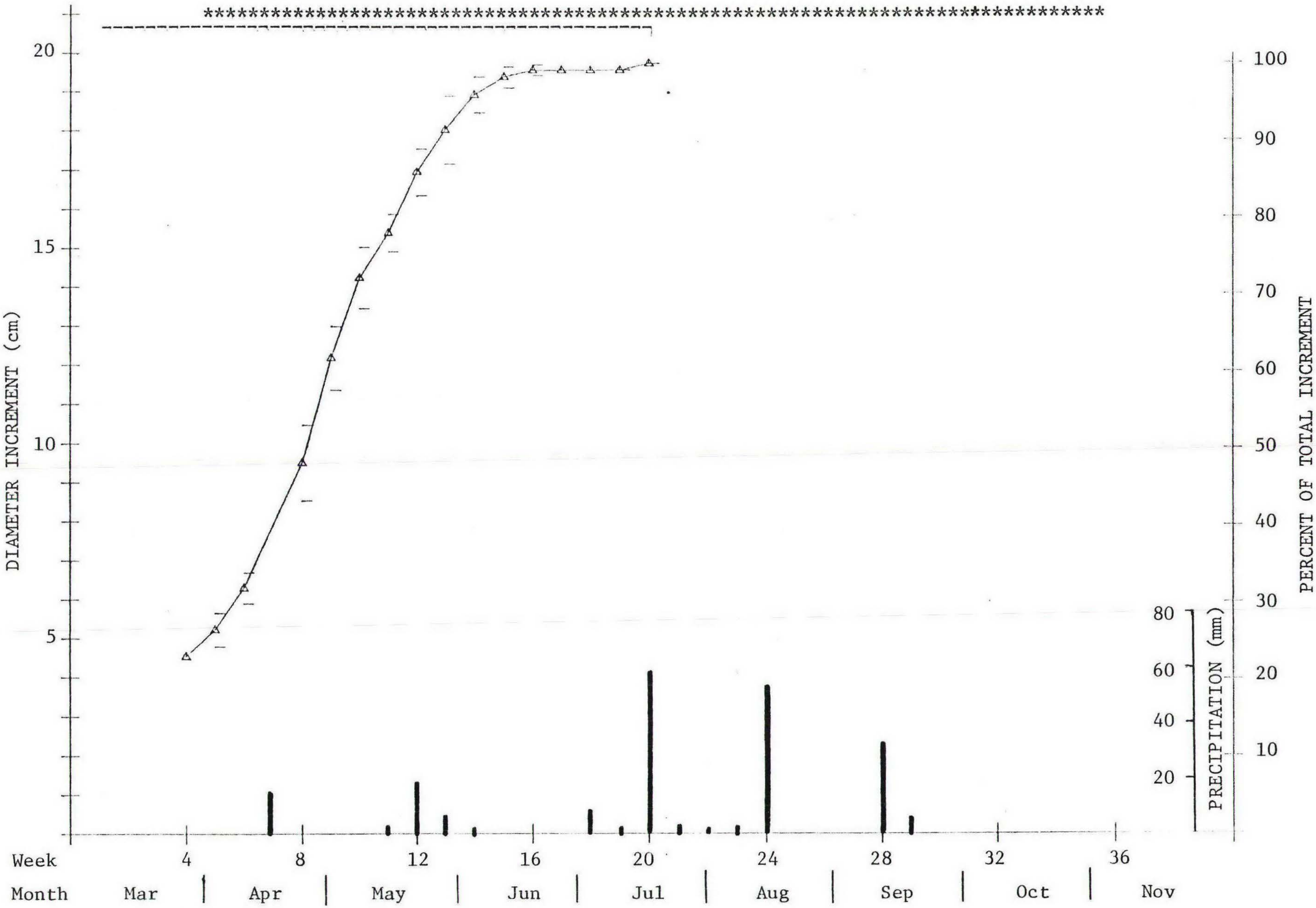

Figure 5. Accumulated weekly diameter increments for purple rollleaf at site B in 1979. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

Since diameter is fairly highly correlated with weight (r = .90) the accumulated diameter increments portrayed in Fig. 5 hold some promise for the derivation of a PAF. The mean 4th week diameter (4.6 cm) is 23.6% of the 16th week diameter (19.5 cm). The reciprocal of .236 is 4.237. Multiplying the 4th week weight (0.03 g) by 4.237 gives an estimate of 16th week weight of 0.13 g. Thus, the estimated mean weight at 16 weeks is .81 g or 85% below the mean weight of the 50 individuals harvested during the 16th week. The implications are that while a straight line relationship between diameter and weight may exist at a given point in time, the relationship is not straight or constant through time.

Two-leaf Senna (Cassia bauhinoides)

Two-leaf senna plants did not appear until the first week in April 1979 (week 5). The first observation was made on April 12 (week 6). At this time the first leaves were fully expanded and stem growth had started. Stem growth was rapid until week 13 when the growth rate was reduced by about 70% (Fig. 6). The major rainfall events in week 20 and 24 resulted in increases in stem growth rate in weeks 21 and 25. After week 28 (September 11) there were no further increases in stem height. Branch development began in week 10 and was complete on all plants by week 24. Evidently in response to the rainfall received in week 20, there was a period of new leaf formation which lasted about 6 weeks.

Flower buds began to develop in week 9. Flowering began in week 10 (May 8) and was complete by week 17. Fruit development extended from week 12 to week 19. Following the precipitation in week 20 there was a second period of flowering beginning in week 22 and extending to week 29. The second crop of pods completed development in week 32. By week 33 most of the plants were dry.

In 1980 the two-leaf senna plants did not begin growth until week 4 (March 24) and some plants did not begin growth until week 8 (April 25). Eight of the plants observed in 1979 did not grow at all. In week 7 several of the plants had brown, curled leaves, indicating frost damage from the below freezing temperature which occurred on April 13. Stem growth was slow and lasted only from week 3 to week 17. The plants attained an average height of 8.4 cm, only half of the height reached in 1979.

Bud development began in week 10 (May 9) and flowering extended from week 13 to week 15. Few pods developed and the plants withered and died back rapidly, some being dry by week 14 and all were dry by week 25 (August 22).

The rainfall events in week 28 resulted in limited regreening of two plants but these had dried again by week 32 (November 8).

On May 4, 1979, 20 two-leaf senna plants were collected. These had an average height and weight of 3.4 cm and .39 g, respectively. On June 6, 1979 50 two-leaf senna plants were harvested and weights determined. The plants had a mean height, diameter and weight of 12 cm, 18.5 cm and 3.12 g, respectively. Individual plant weights ranged from .23 g to 25.82 g. Linear regression analyses showed that height, diameter and volume had R^2 values of .35, .61 and .80 respectively, with weight as the dependent variable.

The May 4 average weight per individual is only 12.5% of the average weight per individual on June 6. Since the May 4 height from the growth curve in Fig. 6 is 48% of the final curve height, it is pointless to carry out calculations of a height-based PAF. A volume (most highly correlated with weight) growth curve cannot be calculated because diameter measurements were not taken on a regular basis for this species.

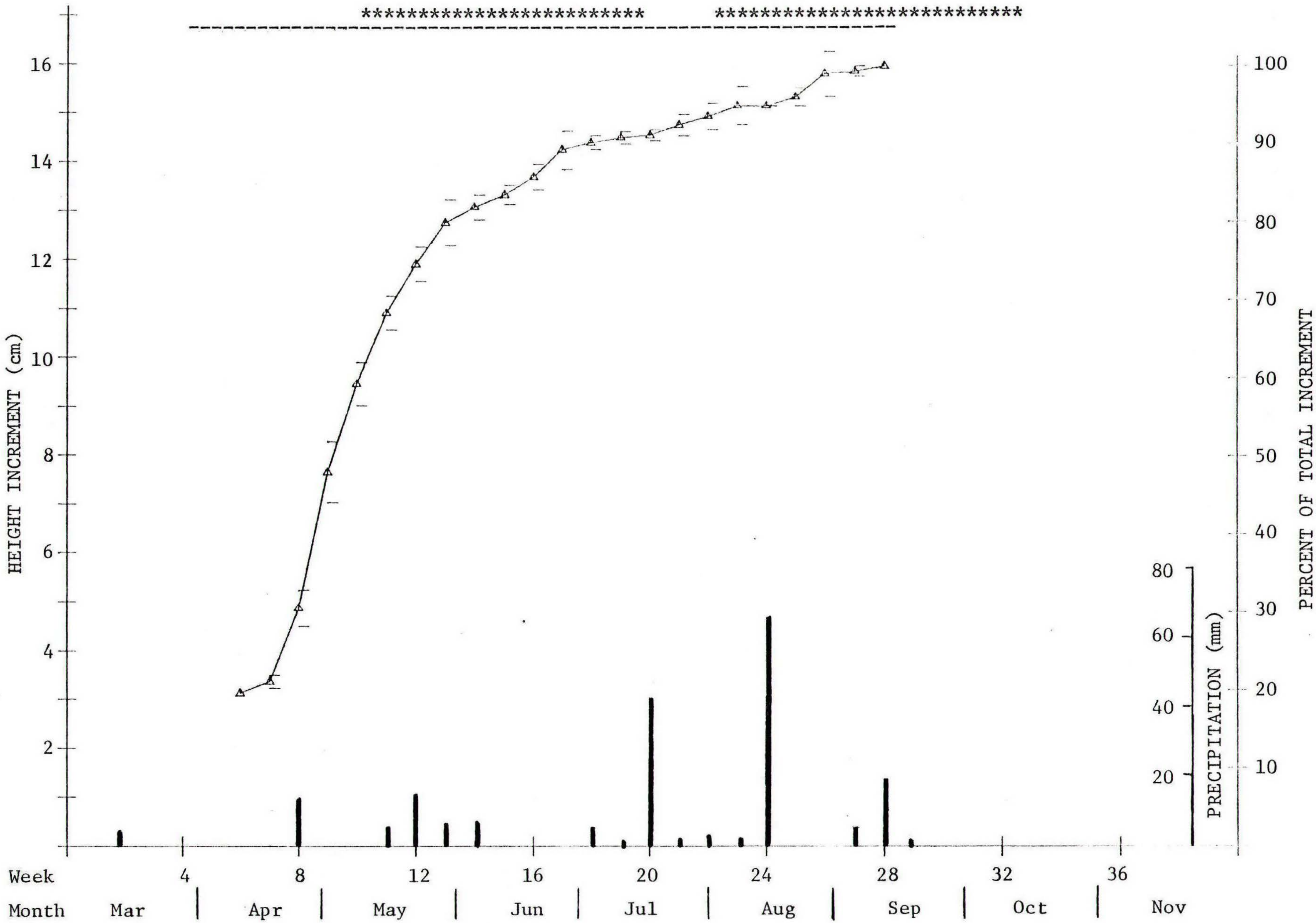

Figure 6. Accumulated weekly height increments for two-leaf senna at site A in 1979. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

Big Globemallow (Sphaeralcea incana)

In 1979, the first observations were made on big globemallow on March 22 (week 4). At this time the plants consisted of a basal rosette of small leaves on short petioles. During week 5 leaves began enlarging and the petioles lengthened but there was no stem elongation. Stem elongation began in week 6 but appreciable stem growth did not occur until week 8 (Fig. 7). Stem elongation and leaf development proceeded at a rapid rate until week 17 (June 28). Growth slowed thereafter until after the rainfall event of July 17 (week 20). The 21st week height increment was 4 times that of the preceding week. Another sharp increase in height increment occurred in week 25. Rainfall events totaling 60.5 mm in week 24 contributed to this increase in growth rate, as did the rapid extension of inflorescences. Growth rate declined steadily after week 25 and growth in height ceased after week 32 (November 9).

Flower bud development began in week 14 and the first flowers opened in week 16. Flowering of the 20 observed plants reached a peak in week 28 (September 13) and was completed in week 32. Fruits continued to ripen until the 39th week. Shedding of the seed was not complete at the last observation.

In 1980, five of the 20 plants observed in 1979 did not grow. The living plants were in a very small rosette form when first observed in week 2 (March 10). As in 1979, a period of leaf expansion and petiole extension preceeded stem elongation. Growth in height proceeded at an accelerating rate until week 12. Thereafter growth slowed and ceased altogether after the 16th week when average stem height was only 14 cm. The plants were heavily grazed by rodents and rabbits. The plants withered and dried during July and by the second week in August there was no green growth left on any plant. Although site B received 22.9 mm of rain (in 6 events) from August 9 to 16, the plants did not regrow. The 26.9 mm of rainfall received from September 9 to 14 did not cause any growth activity in big globemallow.

On September 12, 1979, 50 mature big globemallow plants were harvested and weights for each individual stem determined. The number of stems per plant ranged from 1 to 8 with a mean of 2.8. Individual stems had an average weight of 8.3 g, while the average weight per plant was 23.1 g. Linear regressions were calculated using weight as the dependent variable and individual stem height, average stem height per plant and total stem height per plant as independent variables; the R^2 values were .64, .36 and .59., respectively.

Using the accumulated height increment curve to calculate a PAF we found height on April 27 to be 7.19% of that on September 12. The reciprocal of .0719 is 13.908 which, when multiplied times the April weight per individual, gives 18.1 g as an estimated weight for an individual plant in September vs. the true value of 23.1 g. The estimated value is only 12% short of the true value, a surprising circumstance since the correlation between height and weight was not very high (maximum r = .80).

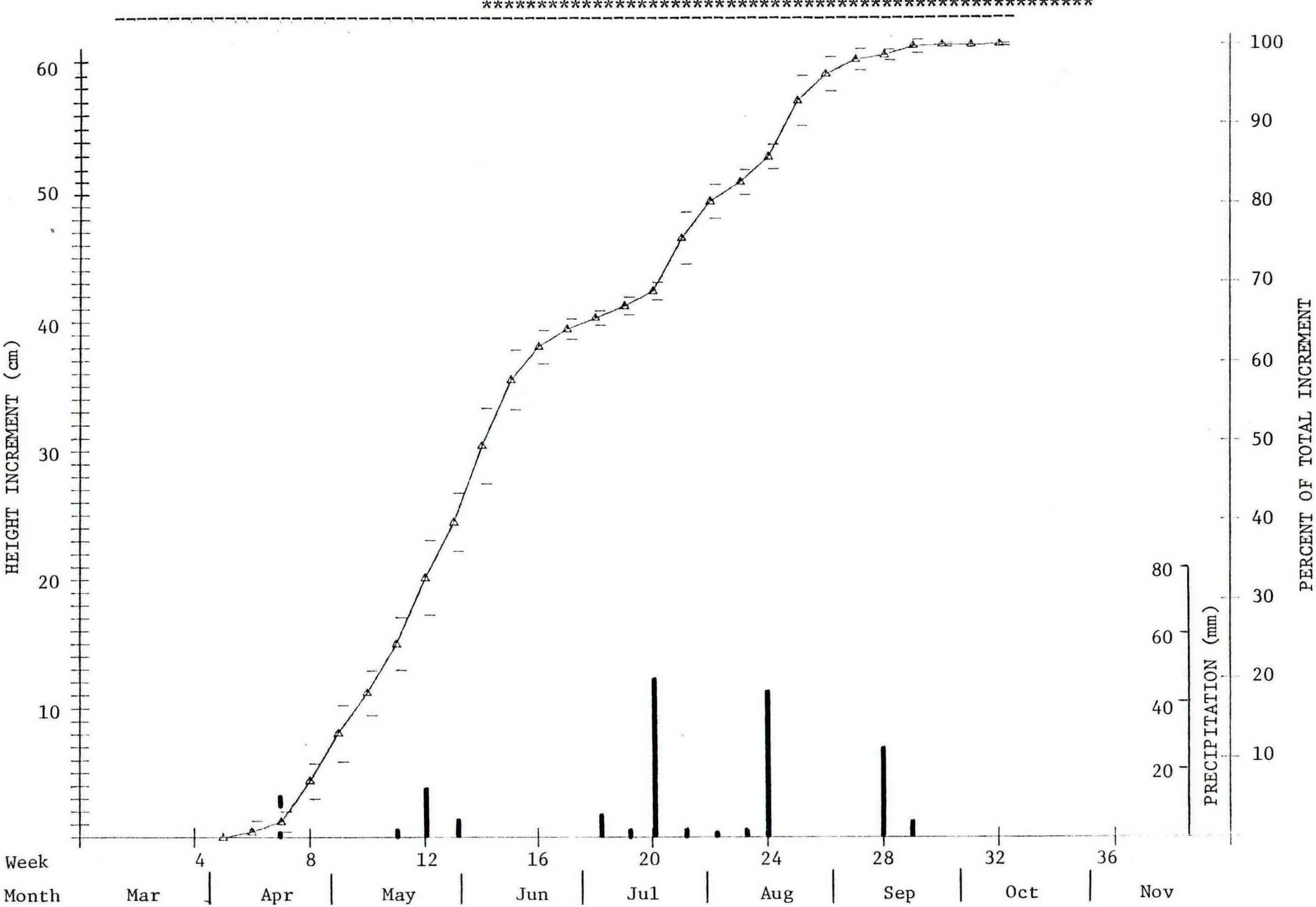

Figure 7. Accumulated weekly height increments for big globemallow at site B in 1979. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

Fourwing Saltbush (Atriplex canescens)

Fourwing saltbush plants are normally dioecious, producing staminate and pistillate flowers on separate plants. The ten plants used for phenological observations were equally divided by sex, five female and five male. A "t" test of the mean weekly increments of male and female plants for the 1979 season did not show a significant difference in growth rates between sexes for the season as a whole. There was slightly more twig growth on staminate plants during the middle and later part of the season.

In 1979 observations began on Mar 27 (week 4). There had probably been a small amount of twig elongation prior to this date. However, only 6 of the 50 twigs showed an elongation during week 5. Most twigs first increased in length during week 6. Once started, twig elongation continued at a relatively constant rate until week 17 (June 26) when the rate declined by about half (Fig. 8). Following the 67.8 mm of precipitation received in week 24, the growth rate increased sharply for two weeks and then declined (Fig. 8). No twig elongation occurred after week 32 (November 9).

Staminate inflorescenses began development in week 6, preceding pistillate inflorescence development by 2 weeks. Staminate flowers had produced pollen and withered by the 16th week. Development of pistillate flowers extended from week 13 to week 22. Fruit development extended through week 38 (November 23). A very heavy seed crop was produced.

In 1980 the observations began in week 2. Only 9 of the 50 observed twigs elongated in week 3 and twig growth was very slow until week 7 (April 18). The twig growth rate was about half of the 1979 growth rate. After week 12 the twigs grew very slowly and all twig growth ceased after week 17 (June 27). All of the plants began to shed leaves in week 18. A very large grasshopper population materially decreased the number of leaves on the fourwing saltbush

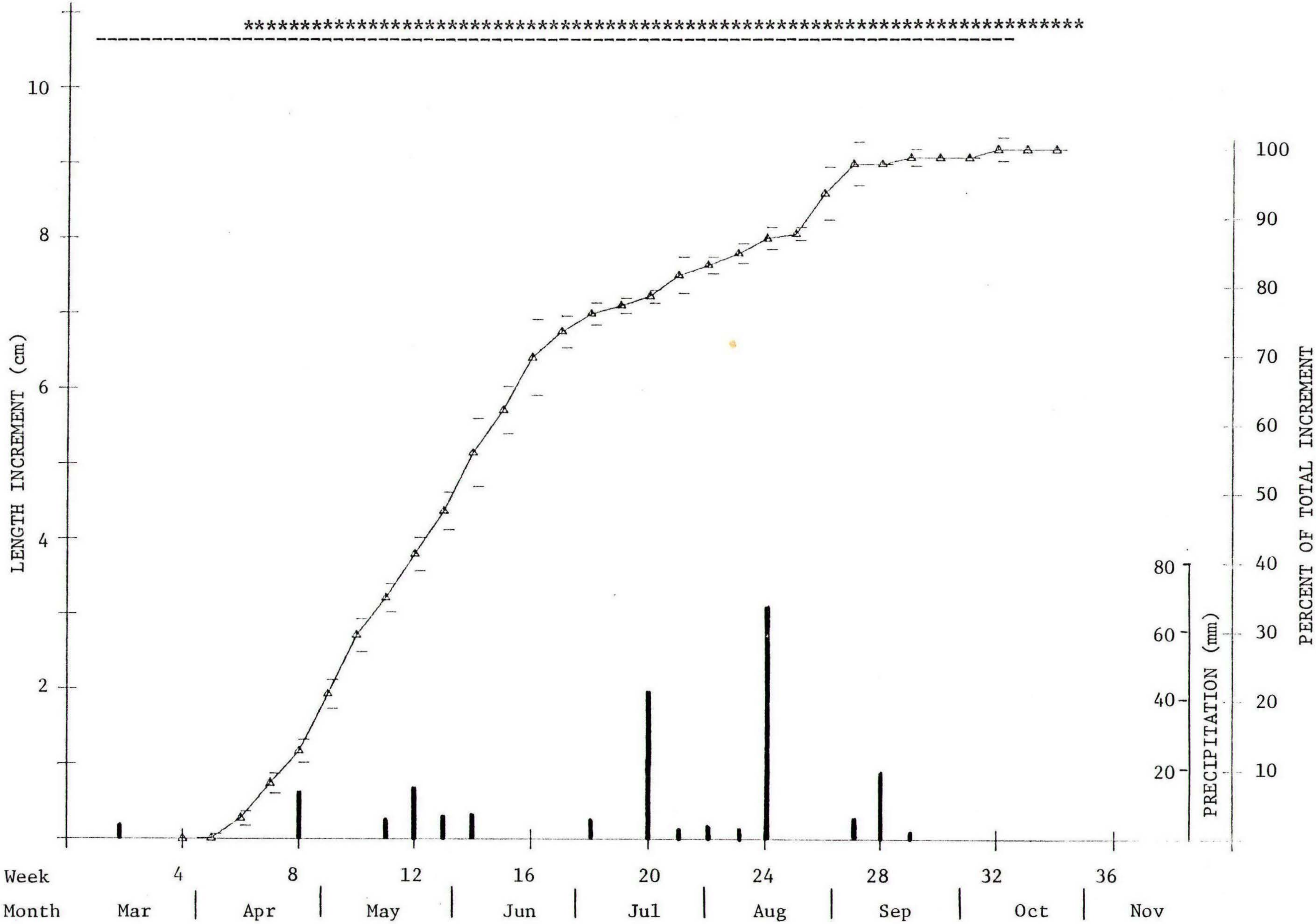

Figure 8. Accumulated weekly length increments for fourwing saltbush twigs at site A in 1979. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

plants. By week 21 (July 25) the observation plants and all other fourwing saltbush plants in the vicinity were completely defoliated. No new leaves appeared during the remainder of the 1980 season.

Inflorescence development began during week 6 for staminate plants and week 8 for pistillate plants, very similar to the 1979 season. However, all inflorescences were stripped by grasshoppers and no seeds were produced in 1980.

In 1979, 20 fourwing saltbush plants, five male and five female plants from dunes, and five male and five female plants from interdunal areas were harvested on August 23 and September 10. Fruits were well developed at this time. Height, widest diameter, height at widest diameter, basal diameter and percentage fit to an inverted cone shape were recorded for dimensional analysis. The plants were separated into component parts, i.e., stems, branches, leaves, fruits, and oven dried and weighed.

Total weight of the 20 fourwing saltbush plants ranged from 332 g to 8075 g. Dead wood made up from 2 to 49% of the total plant weights. Total live weight ranged from 201 g to 6058 g. On the female plants the fruits constituted from 6 to 22% of the live weight. Leaves constituted from 4 to 32% of the live weight. It would appear that no matter what part of the shrub is considered, its proportion of total live weight of plant varies greatly.

Linear regression analyses were used to explore the relationships between various dimensions or volumes and the total live weight of the shrubs. Cylinder volume was calculated from maximum diameter and height. The volume of an ice cream-cone shape, was calculated. This consisted of the volume of an inverted cone from the ground to the height of maximum diameter ($1/3\ \pi\ r^2h$) plus the volume of a upper-half spheroid ($4/3\ \pi\ r^2h$) for the height of the shrubs above the height of maximum diameter. Using non-transformed data the

cylinder volume and cone + spheroid volume had coefficients of determination (R^2) of .76 and .77, respectively. Adjustment of live weight by an estimated fit-to-cone shape factor made in the field decreased rather than increased the R^2 value. Log_{10} transformations were made of both volume and live weight. Linear regression analyses using the transformed data yielded R^2 values of .84 and .86 for cylinder volume and cone + spheroid volume, respectively. While cone + spheroid volume will explain a little more of the variability in fourwing saltush live weights than will cylinder volume it is doubtful if the difference is enough to warrant the extra computations. The relationship between the transformed cylinder volume and weight are shown in Fig. 9.

A PAF for saltbush is not easy to arrive at. The plant is essentially evergreen in this area and except for dry periods the leaf biomass remains fairly constant. The extreme variability among plants in weight of leaves makes it difficult to even estimate a weight-based adjustment for leaf replacement following any leaf shed period. The annual increment of twig growth is a very small proportion of the total live biomass. All of what appeared to be current twig growth was removed from three of the harvested plants. The current twigs made up only 2 to 3% of total live weight in each case. It appears that an adjustment for current production would be less than the error associated with determination of standing crop biomass of fourwing saltbush. Relative age of plants as determined by counts of growth increments (rings) did not show a significant correlation with live biomass.

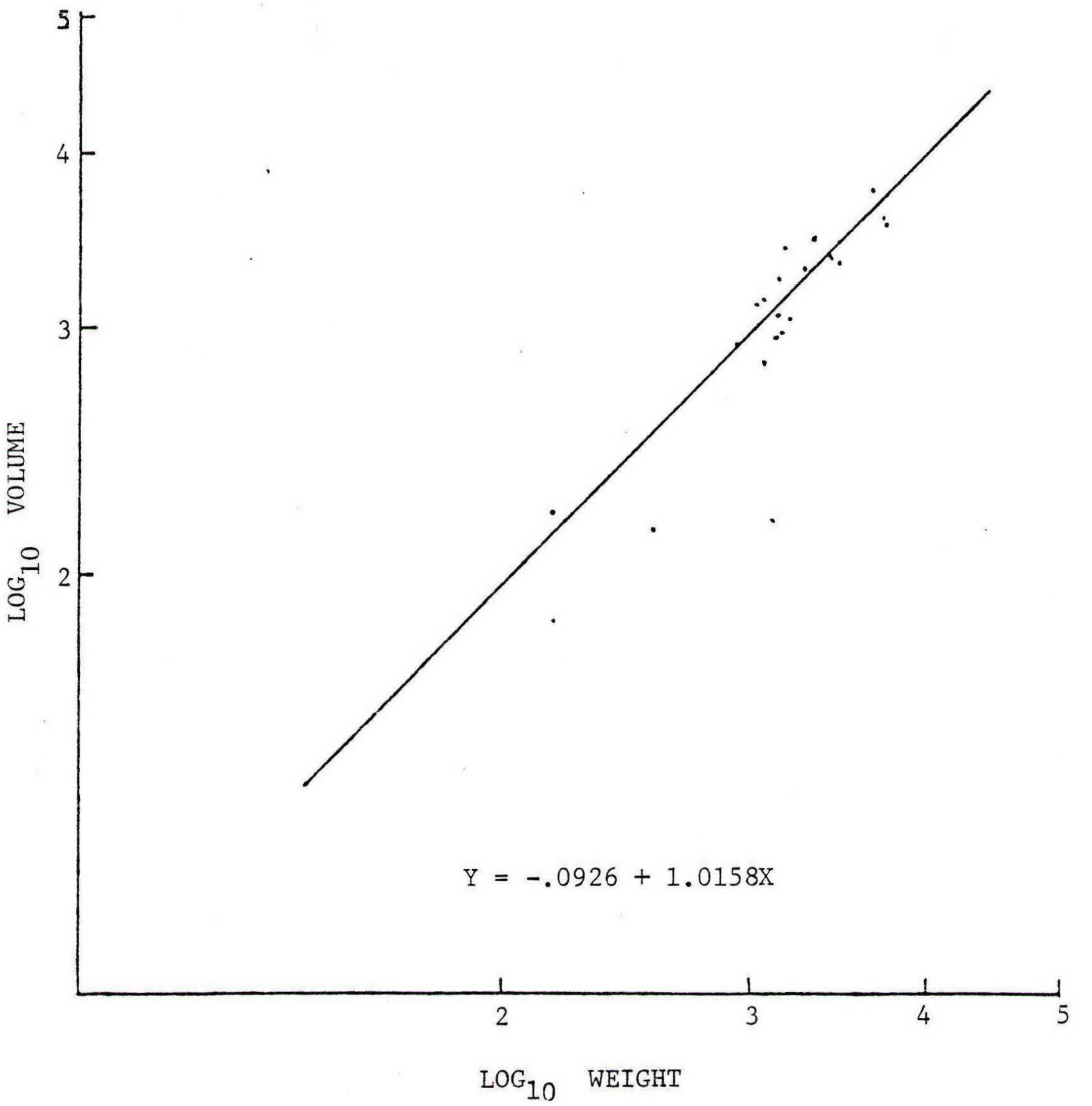

Figure 9. Relationship between $\log_{10}$ volume ($\pi r^2 \times h$) and $\log_{10}$ total aboveground weight for 20 fourwing saltbush plants.

Honey Mesquite (*Prosopis glandulosa*)

When honey mesquite was first examined on March 22, 1979 there was no growth activity. Leaf buds began to swell in week 4 and leaves started to emerge in week 5 (April 4). Leaf development reached a peak in week 9 and no leaf growth was observed after week 21. Inflorescence development started in week 5 and flowers were evident in week 10. Blooming was complete by week 16 and pods, of which there were very few, were matured by week 24. Individual twigs of mesquite were not tagged for measurement because of the difficulty in determining which twigs would continue to increase in length. The observable period of twig elongation extended from week 10 to week 21. Leaf shedding began in week 28 (September 11) and was complete by week 37 (November 13).

In 1980 honey mesquite began growth somewhat earlier than in 1979. Leaf buds began to swell in week 3 and leaves began to emerge in week 4 (March 24). Some frost damage occurred due to the low temperature on April 18 but it was superficial and had no apparent lasting effect. Leaf opening and expansion was essentially complete by week 13 and did not continue into the summer as it had in 1979. Blooming began at the same time as it had in 1980 (week 10). However, when the inflorescences were blooming profusely they were completely stripped of blossoms by grasshoppers. Not a single fruit developed, not only on the plants observed, but on all plants within several square miles. Some leaf shedding occurred as early as week 29 but the major portion of the leaves were shed in weeks 39 and 40 (end of November). The last leaves did not fall until about December 13.

In 1979, five honey mesquite dunes were sampled during July to determine aboveground biomass. This was done by clipping a pie slice-shaped wedge in the cardinal directions on each dune. The point of the wedge-shaped clipping frame was placed at the center of the dune and the angle subtended by sides of

the frame (18.4°) included a proportional sample of the center and periphery of the circular-shaped mesquite dunes.

The biomass per m^2 was calculated for each directional sample and the directional samples averaged to obtain an average yield per m^2 for each plant. Total live biomass ranged from 1108 g/m^2 to 2041 g/m^2 on the five dunes. The overall average was 1518 g/m^2 (SE = 155 g/m^2). Standing dead biomass averaged 444 g/m^2 (SE = 67 g/m^2) for the five dunes. In the best case, fruits contributed 0.5% of total live weight. Leaves made up from 16 to 29% of the total live weight with an overall average of 22%.

In connection with another project the biomass on an entire mesquite dune was sampled during August 1980. Total area of the canopy was 43 m^2 and there were 710 living mesquite stems. The total weight of live material was 630 g/m^2 and there were 289 g/m^2 of standing dead material. Although there was less biomass per m^2 than on the dunes sampled in 1979 leaves again constituted 22% of the total live weight.

No dimensional analyses were made for honey mesquite. Ludwig, Reynolds and Whitson (1975) determined equations for honey mesquite biomass which are applicable. Contributions to biomass by twig growth are believed to be very small (1-3% per year). Leaf replacement is the major phenological event affecting biomass and is essentially a have or have not situation. In situations where the mesquite stems on dunes are from .5 to 1 m in height an adjustment of 20-25% of standing live biomass appears appropriate for leaves.

Broom Snakeweed (Xanthocephalum sarothrae)

Broom snakeweed is a half-shrub which is essentially evergreen in nature in this locality. Branchlets were tagged on March 27, 1979. At this time the new banchlets averaged 3 cm in length. Growth proceeded at a rapid and fairly constant rate until week 15 (Fig. 10). The rainfall events in weeks 20 and 24 caused small increases in the rate of branchlet growth in the weeks immediately following the events, but the growth rate remained low until branchlet length increases ceased in week 27.

Flower bud development was first detected in week 27 although it probably began a week earlier. Flowering reached a peak in week 30 (September 25) and had ceased by week 32. Fruit development and maturation continued until week 36 (November 6).

In 1980 broom snakeweed branchlets were tagged in week 1 (March 7). At this time the branchlets averaged only 1.6 cm in length. The rate of length increase was fairly slow until week 7 when it increased and proceeded at a rapid rate until week 14 (Fig. 11). The 28 mm of precipitation received in week 9 was followed by sharply accelerated growth in weeks 10 and 11. However, the precipitation events occurring from weeks 19 to 27, none of which were greater than 8 mm, had no detectable influence on branchlet growth rate. Even the 30 mm of rain in week 28 (Sept. 7-13) did not result in accelerated branchlet growth.

Flower bud development was detected in week 27, the same as in 1979. Flowering was much less profuse than in 1979 and reached a peak in week 32, about 2 weeks later than in 1979. A few flowers continued to bloom until week 36. By week 37 (November 12) most fruits were mature, and growth and reproductive activity ended for the season.

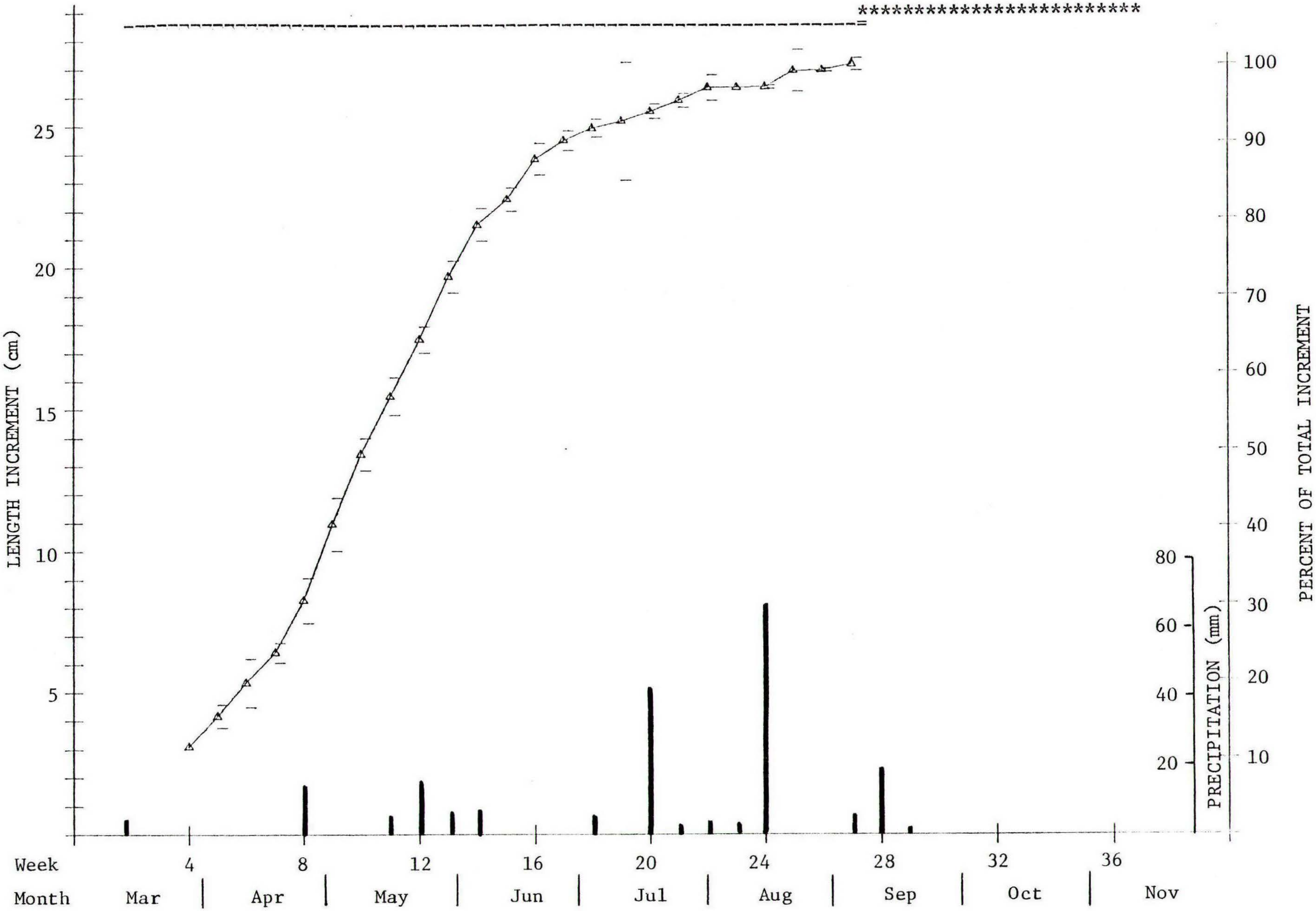

Figure 10. Accumulated weekly length increments for broom snakeweed branchlets at site A in 1979. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

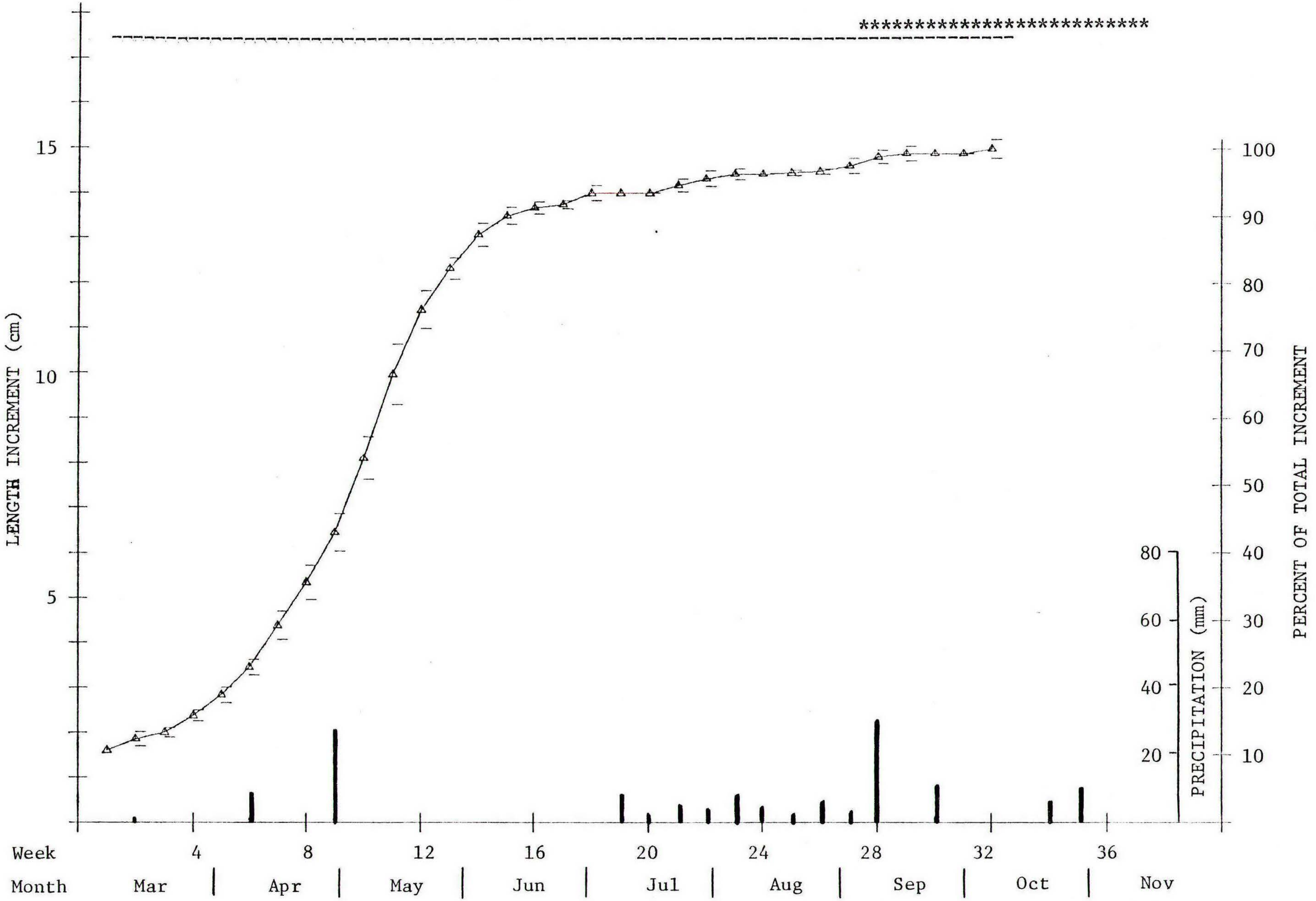

Figure 11. Accumulated weekly length increments for broom snakeweed branchlets at site A in 1980. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

Collections of broom snakeweed plants were made on May 30, 1979, November 3, 1979 and November 13, 1980. At each collection date all totally live broom snakeweed plants encountered in a randomly selected belt transect 1 m wide were harvested until 50 plants were obtained. Partially decadent plants were excluded from the sample. Diameter and height measurements were made for each plant. The plants were separated into branches developed during the current season and the basal portion developed in previous seasons. The base of course, contained a small increment of diameter growth which occurred during the season of harvest.

Characteristics of the three samples of broom snakeweed are presented in Table IV. Linear regression analyses revealed a fairly close relationship r = .88 to .96) between upper half spheroid volume and plant weight, both total weight and new growth weight. Use of an inverted cone volume for the base of the plant, topped by spheroid volume for the top of the plant did not explain more of the variability in weight. Likewise, $\log_{10}$ transformations of weight and volume data did not explain more of the variability in weight of plants. The R^2 values obtained (Table IV) were very similar to the R^2 (.90) found for spheroid volume and weight by Ludwig, Reynolds and Whitson (1975) with a sample of 10 plants.

Using the branch increment curve of Fig. 11 to derive a PAF, we find the May 5 (week 9) length to be 10.9 cm which is 40% of the final branch length of 27.2 cm. The reciprocal of .40 is 2.5. If the mean weight of broom snakeweed plants harvested on May 5 (20.08 g) is multiplied by 2.5 the projected weight for the end of the season is 50.2 g vs. the actual weight of 105.32 g. Plant diameter increments, which would have permitted the testing of a volume based PAF, were not determined.

Table IV. Average biomass of broom snakeweed plants collected in 1978 and 1980 and linear regression equations using upper-half spheroid volume ($4/3 \pi r^2 h$) as an independent variable to predict biomass. The coefficient of determination is R^2.

Collection Date	Number of plants	Mean total weight (g ± SE)	Mean weight new growth (g ± SE)	Mean growth (percent of total weight)	Linear regression equation (spheroid volume = X: weight = Y)	R^2
May 5, 1979	50	20.08 ± 2.05	12.75 ± 1.31	63	Y(total weight) = 3.1823+.7345X	.87
					Y(new growth weight) = 1.8033+.4760X	.89
Nobember 3, 1979	50	105.32 ± 13.7	93.46 ± 11.38	89	Y(total weight) = 3.9272+.8552X	.80
					Y(new growth weight) = 10.890±.6965X	.77
November 11, 1980	50	69.30 ± 7.51	36.66 ± 3.59	53	Y(total weight) = 4.0450+.7893X	.92
					Y(new growth weight) = 7.5642+.3519X	.80

Fluffgrass (<u>Erioneuron pulchellum</u>)

The diminutive size of fluffgrass made it a difficult species to work with. The small, closely packed culms could not be marked individually and non-destructive counts of leaves were difficult. When the first observations were made on March 27, 1978 the culms were 1-2 cm high and had 2-3 leaves. The elevated stolons which characterize fluffgrass began to appear in week 9. Development of stolons increased plant height until week 27, when the observed plants had an average height of 9.4 cm. The inflorescences began to develop in week 23 and seeds were mature by week 31. Shedding of seed was complete by week 34 and the plants largely dry and dormant.

In 1980 the fluffgrass plants had 2-3 fully expanded leaves per culm when first examined on March 7. Growth was slow and by week 9 the new culms were only about 3.5 cm in height with 4-6 leaves. The first pair of leaves were already dry. In week 11 a few of the plants began to develop elevated stolons, but these grew very slowly. From week 15 to 20 the plants slowly dried and died back. In week 20 estimates made on each individual plant showed that on the average only 16% of the bunch or plant area remained green. The light showers which occurred from weeks 19 to 27 resulted in new leaf formation on a few plants but by the end of the season only 9 of the 20 plants were alive. Inflorescences did not develop until after the 30 mm of precipitation received in week 28. The number of culms developing inflorescences were few and flowering occurred in week 31. By week 35 growth and reproductive activity was finished. The average maximum height attained by the plants was 5.3 cm, compared to the average height of 9.4 cm attained in 1979.

On September 18, 1979, 50 fluffgrass plants were collected, separated into live and dead components, and weighed. Very few seeds had been shed at this time so the plants were at about maximum biomass for the season. On the

average, 94% of the weight of plant material was current growth. Height of plant was not correlated with weight. Basal area of the plants had a fairly high correlation with weight ($r = .89$) for both current growth and total weight. The average weight per cm^2 of basal area was .17 g.

In 1980, 50 individual culms of fluffgrass were collected on March 20, May 5 and June 2, and 100 culms were collected on November 11. The number of leaves, length and weight were determined for each culm individually. The individual culms were sorted into two groups, reproductive (boot stage or with inflorescense) and vegetative. The vegetative stage was sorted into 2 cm height classes (Table V). Linear regression analyses were made using the mid-point of each height class ($\bar{x}$ for reproductive class) and leaf number as the independent variables and weight as the dependent variable. The coefficients of determination (R^2) were .88 and .93 for culm length and number of leaves, respectively.

While there is apparently a strong relationship between culm length and weight in fluffgrass, it is difficult to take advantage of the relationship. Precise field measurements of the very small culms are difficult to make. Yet if the average culm length per plant could be determined or average number of leaves per culm, an estimate of biomass could be made. It must be remembered that the relationships are based on plants collected during a relatively poor season for growth. The relationships between length and weight or number of leaves might be different in a year with greater plant growth.

Table V. Average culm weights and average number of leaves per culm for vegetative fluffgrass culms in 2 cm length classes and a reproductive culm class (infloresence developing or present).

Length class >cm <cm	N	Number of leaves $\bar{x} \pm SE$	Weight in grams $\bar{x} \pm SE$
0 - 2	9	3.13 ± .18	.003 ± .0004
2 - 4	83	3.00 ± .12	.006 ± .0003
4 - 6	71	4.06 ± .18	.011 ± .0004
6 - 8	6	5.17 ± .60	.016 ± .0023
8 - 10	1	8.00	.044
Reproductive Class			
Mean Length = 7.9 cm	80	11.78 ± .67	.043 ± .0033

Plains Bristlegrass (*Setaria macrostachya*)

The first observation of plains bristlegrass on March 28, 1979 found the plants with an average culm length of 9.4 cm. Growth was very rapid until week 8 (April 26) and then proceeded at a slow rate for 12 weeks (Fig. 12). The precipitation which occurred in weeks 20 and 21 totaled only 19 mm but caused an increase in culm growth rate during weeks 21 and 22 (Fig. 12). Following the 39 mm of rain in week 24 there was a very sharp increase in rate of culm growth but by week 31 culm growth had ceased. The accumulated weekly increment of leaf development shows a curve closely paralleling that of culm length (Fig. 13).

Some of the culms began to produce inflorescences as early as week 16 (June 21). However, most of the culms did not produce inflorescences until after the rainfall which occurred in week 24. Inflorescence development continued until week 29. Shedding of seeds extended from week 25 to week 38. By December 1 the plants had dried back to the stem bases which apparently remain green throughout the winter.

In 1980, observations of plains bristlegrass began on March 6 (week 1) when the culms were 5.5 cm in length. Growth was very rapid for four weeks but then declined sharply. Increase in culm length was very erratic through the rest of the season (Fig. 14). Major rainfall events in weeks 23, 24, 28, and 29 were followed by increases in weekly growth rates. Many culms died during the season and the plants often had a brown rather than green color due to dead culms and extensive drying of leaf tips. Weekly increment in number of leaves followed a pattern similar to culm height (Fig. 15). It can be seen that after week 13 only one full leaf was added during the remainder of the season. Average culm height was 3 cm less in 1980 than in 1979 and the culms averaged about 1 leaf less per culm in 1980 than in 1979.

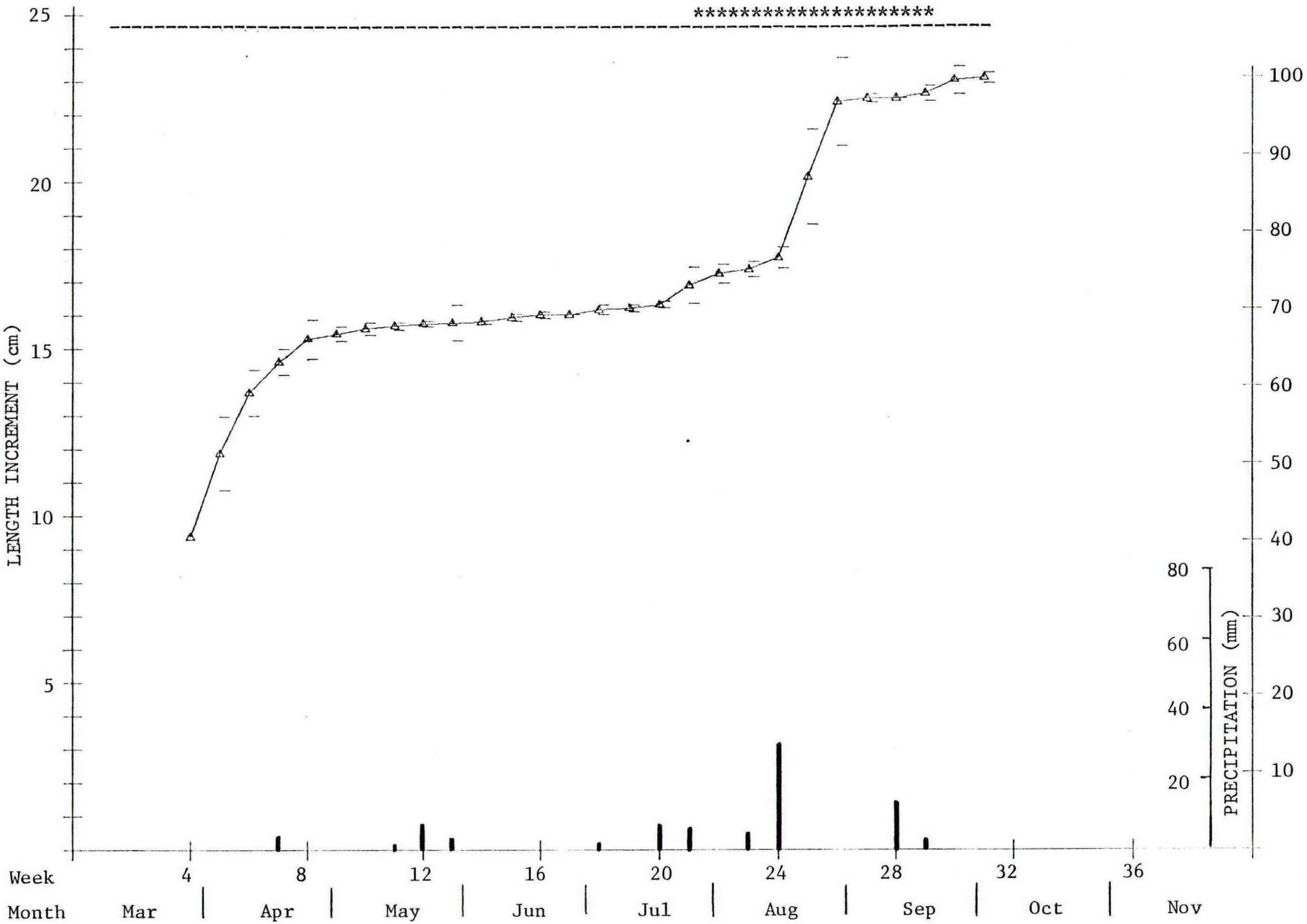

Figure 12. Accumulated weekly length increments for plains bristlegrass culms at site C in 1979. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

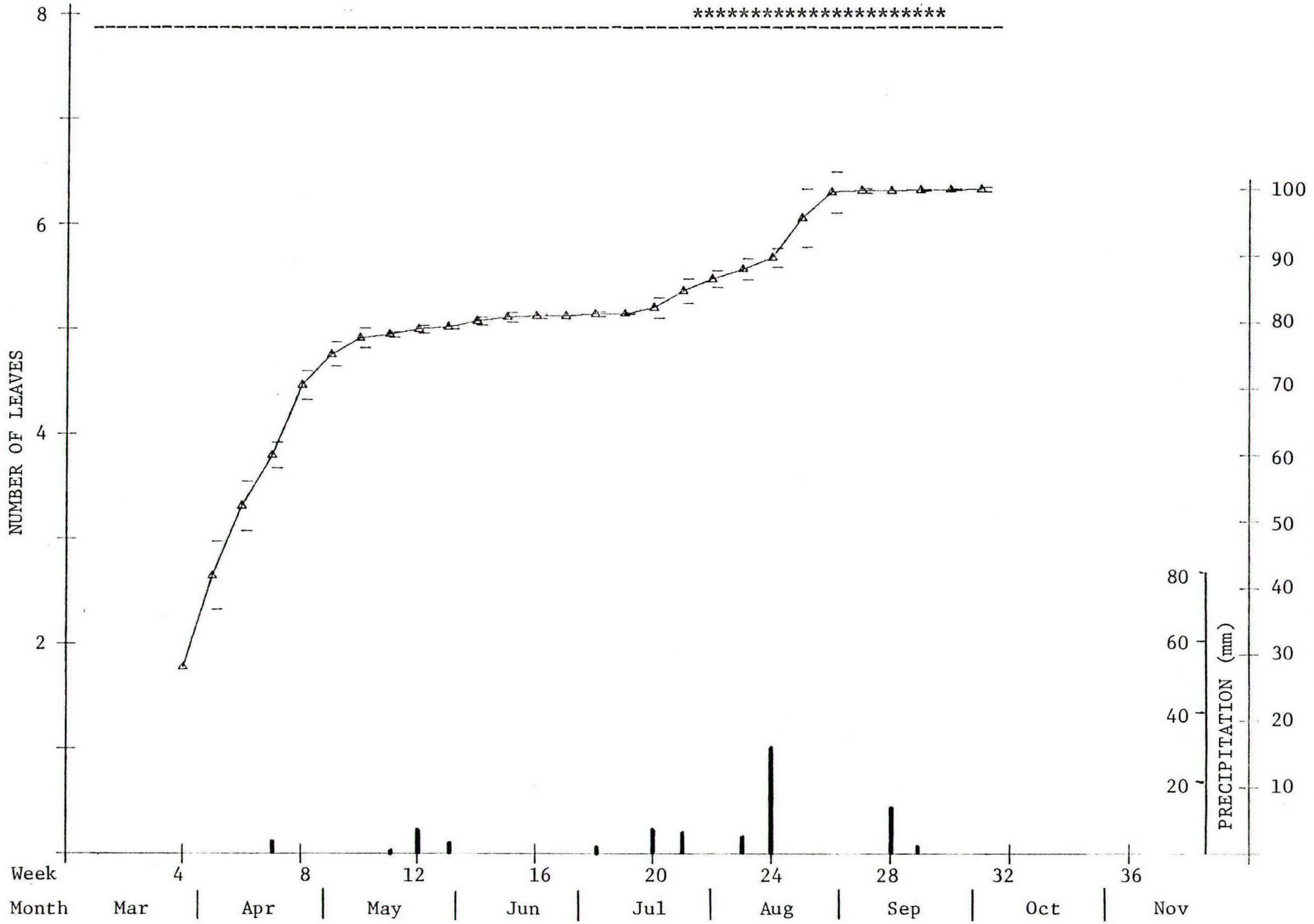

Figure 13. Accumulated weekly leaf increments for plains bristlegrass at site C in 1979. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

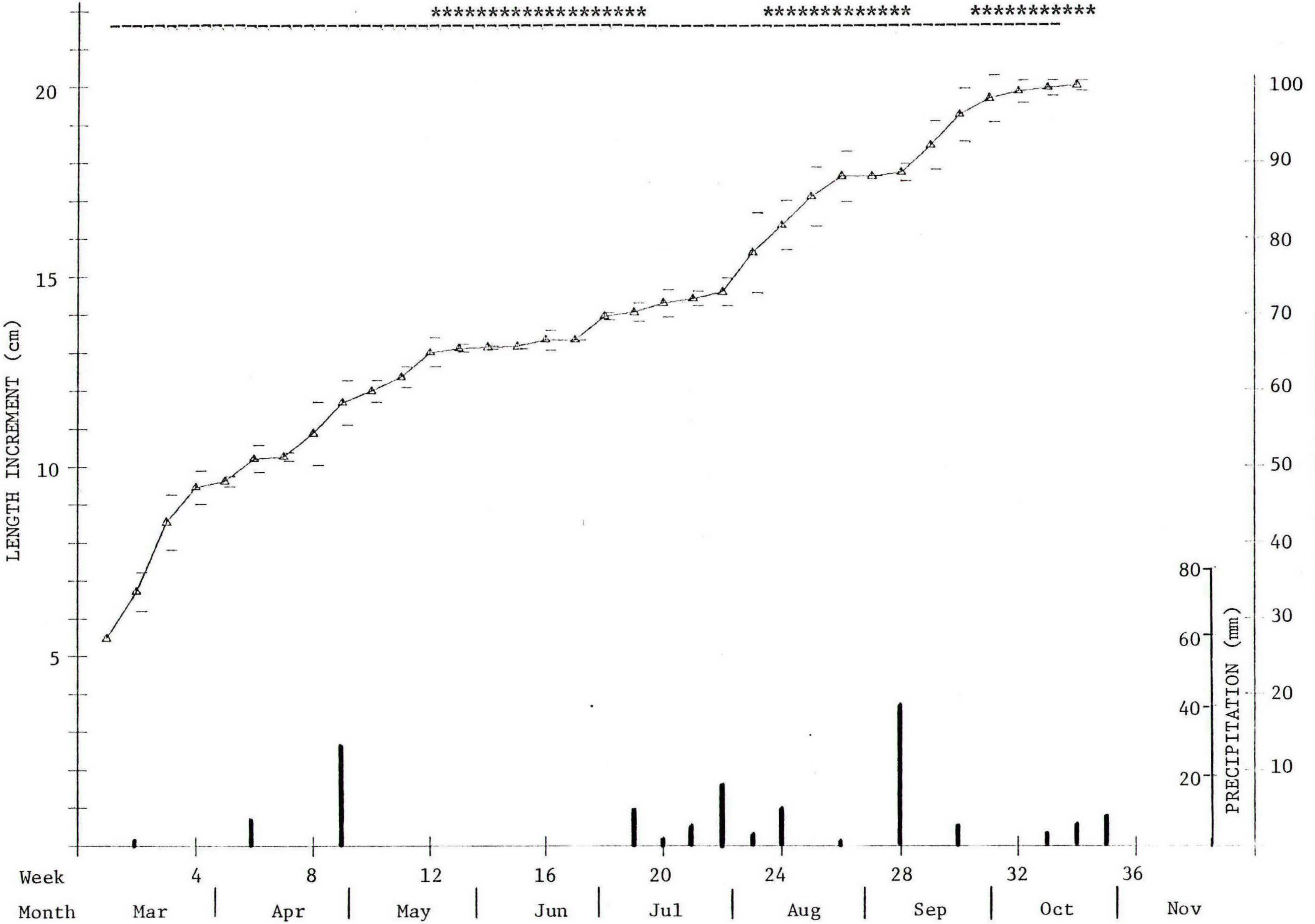

Figure 14. Accumulated weekly length increments for plains bristlegrass culms at site C in 1980. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

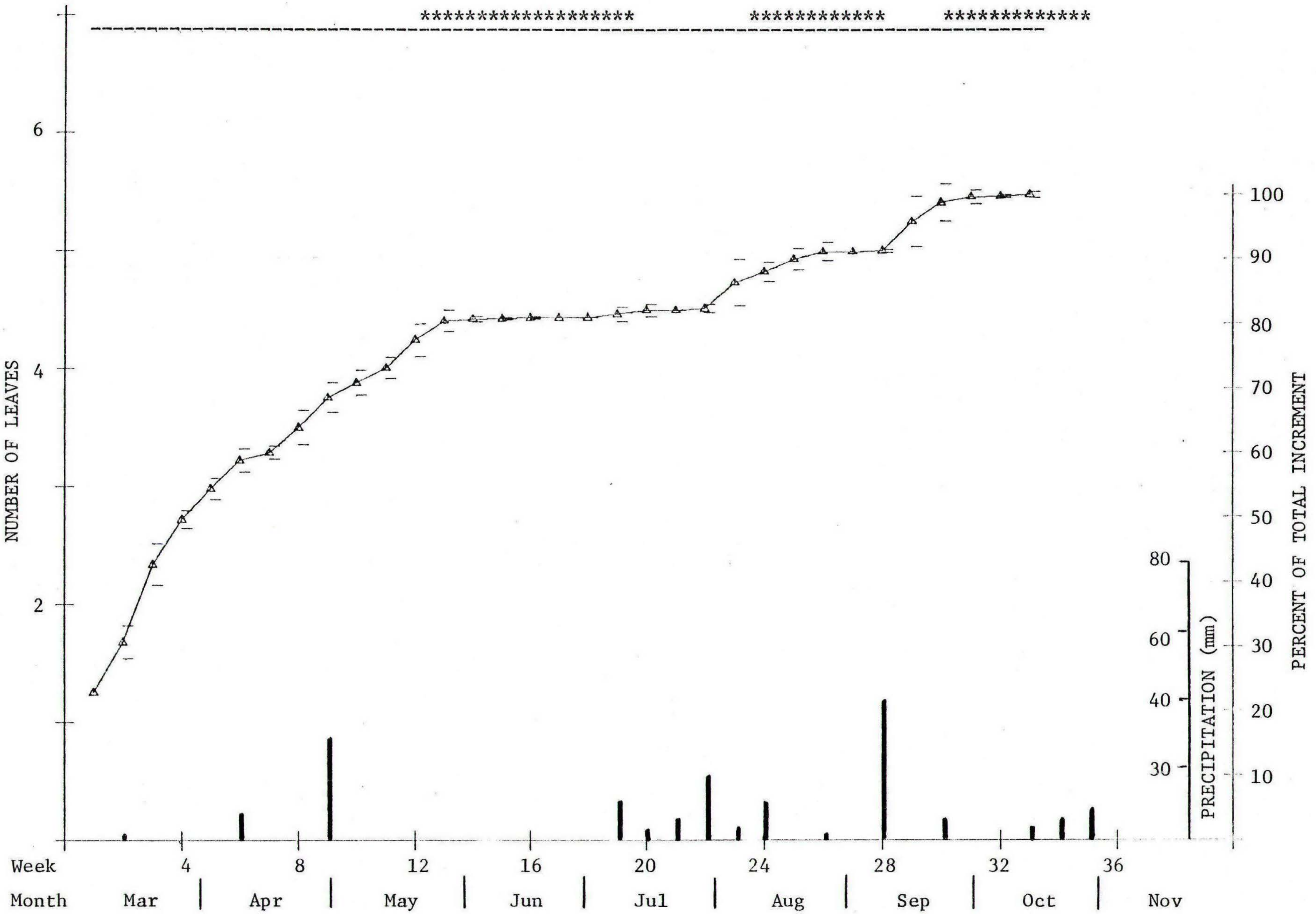

Figure 15. Accumulated weekly leaf increments for plains bristlegrass at site C in 1980. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

The first inflorescence appeared in week 12 and had matured by week 17. Additional seed heads appeared in week 16 and matured by week 19. More inflorescences appeared in weeks 23, 24, 25, 30, 31, and 32. All had matured and shed their seed by week 39. Thus, reproductive activity in 1980 began earlier than in 1979. Reproductive activity was similar in both years in that it was spread over a long period and was not separate and distinct from the vegetative growth period.

On September 20, 1979, 20 plains bristlegrass plants were harvested, separated into current years growth and dead material from previous seasons. Basal area of the plants ranged from 5 to 140 cm^2 with a mean basal area of 35 cm^2. Average height of the plants was 59 cm (range 40-101 cm). Average weight of current growth was 9 $\pm$ 1.9 g per plant. Average weight of current growth per cm^2 of basal area varied as much as weight per plant, ranging from 0.08 to 2.08 g., with an average of .57 $\pm$ .12 g. Linear regression analyses were performed to determine the relationships between plant weights and basal area, plant height, and volume (basal area X height). Both basal area (r = .70) and volume (r = .76) were correlated with total plant weight.

The coefficients of determination (R^2) for total plant weight with volume and basal area were .57 and .49, respectively. The R^2 for current growth weight with volume and height were .02 and .60, respectively. Basal area had no correlation with current growth weight and height had no correlation with total plant weight. The inability of any of the dimensional parameters to account for more than 60% of the variation in weight of current growth means direct determinations of production (clipping) are likely to continue.

In 1980, three collections of about 100 culms each were made of plains bristlegrass in March, May and August. Height, number of leaves and weight were determined for each culm. The culms were sorted into vegetative and

reproductive classes and the vegetative class divided into 4 cm length classes (Table VI). Linear regression analyses using the mid-point of length classes, average length of the reproductive class and number of leaves as independent variables and mean culm weights as the dependent variable were performed. The coefficients of determination (R^2) for weight with class lengths and leaf number were .84 and .95, respectively. Thus, either culm length or number of leaves account for a high percentage of the variability in average class weight of culms.

Apparently there is a strong relationship between culm lengths and culm weights. It would be relatively easy to establish a PAF by setting the mean weight of current growth per plant in 1979 as equal to 100 percent height and use the height increment curve for 1979 (which is in fact an average of culm heights) as an index to weight increase through the season. The basic problem is that such a PAF would apply to the 1979 season and no other.

Table VI. Average culm weights and average number of leaves per culm for vegetative plains bristlegrass culms in 4 cm length classes and a reproductive culm class (inflorescence developing or present).

Length class $>$ cm $<$ cm	N	Number of leaves $\bar{x} \pm SE$	Weight in grams $\bar{x} \pm SE$
0 - 4	11	.8 ± .22	.005 ± .0007
4 - 8	44	1.7 ± .08	.011 ± .0006
8 - 12	50	2.2 ± .11	.020 ± .0011
12 - 16	37	2.8 ± .15	.038 ± .0025
16 - 20	49	3.5 ± .15	.059 ± .0028
20 - 24	26	3.6 ± .14	.075 ± .0049
24 - 28	19	4.2 ± .31	.121 ± .0112
28 - 32	5	4.5 ± .52	.137 ± .0180
32 - 36	5	7.1 ± .85	.310 ± .0594
36 - 40	6	5.5 ± .83	.281 ± .0423
40 - 44	4	6.2 ± .68	.403 ± .0589
44 - 48	2	8.5 ± .50	.543 ± .0815
Reproductive Class mean length = 41.8 cm	48	8.0 ± .35	.553 ± .0330

Bush Muhly (Muhlenbergia porteri)

Bush muhly has perennial, wiry, much branched culms from a hard, knotty base. A large portion of the wiry stems remain alive during the winter and new growth consists primarily of new branches originating at nodes on the perennial stems. Observations of bush muhly began on March 29, 1979 (week 4). At this time the new culm branches averaged 5.3 cm in length and had an average of 3.8 leaves. The rate of branch growth was very rapid through week 10, averaging 2.8 cm per week (Fig 16). Rainfall during weeks 11 and 12 apparently resulted in an increased growth rate during weeks 14, 15, and 16. Following this, branch growth came to a virtual standstill. Branch growth did not increase after the 19.7 mm of precipitation received in week 14, probably because most of the precipitation occurred in a single, high intensity storm and most of the water was lost as runoff. Growth accelerated sharply in weeks 21 and 22 following the 13 mm of rain received in week 20 but the rate of growth declined in week 23 and 24. During week 24, 60 mm of rain were received and this was followed by another period of accelerated growth in weeks 25 thru 27. By week 31 increase in length of culm branches had ceased.

The pattern of leaf development was very similar to branch length (Fig. 17). However, no new leaves were formed after week 27. There was an average of 16.4 leaves per branch by the end of the season. Not all of these were green. Characteristically the first leaf developed, and often the first four or five, dried fairly early in the season. Inflorescences first began to appear in week 22 (July 31). Additional inflorescences developed in week 23 and the major portion appeared in week 26 (August 28). Seeds were mature and shed by week 37 (November 15). Inflorescences were very abundant and the seed crop was large.

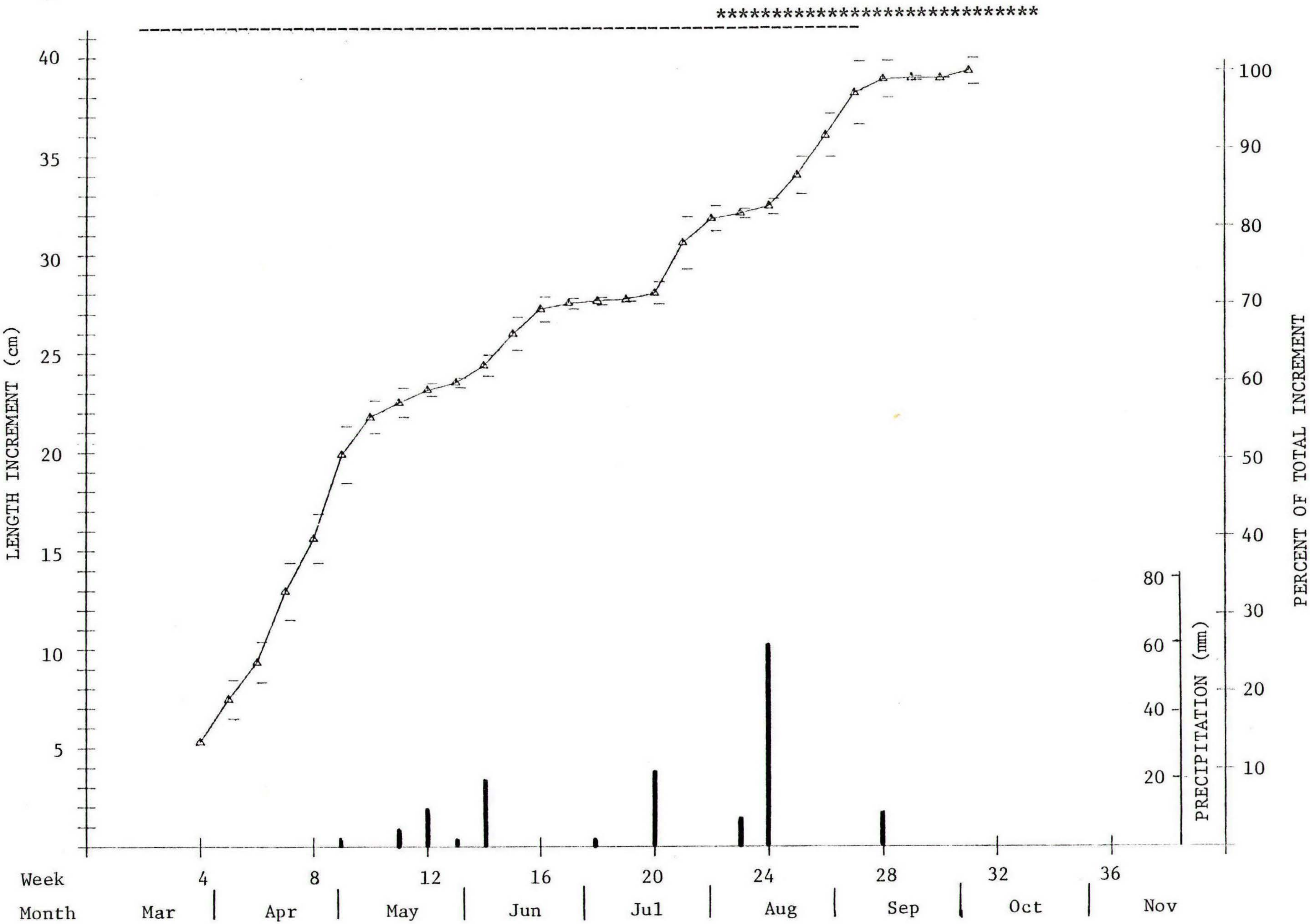

Figure 16. Accumulated weekly length increments for bush muhly culms at site D in 1979. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

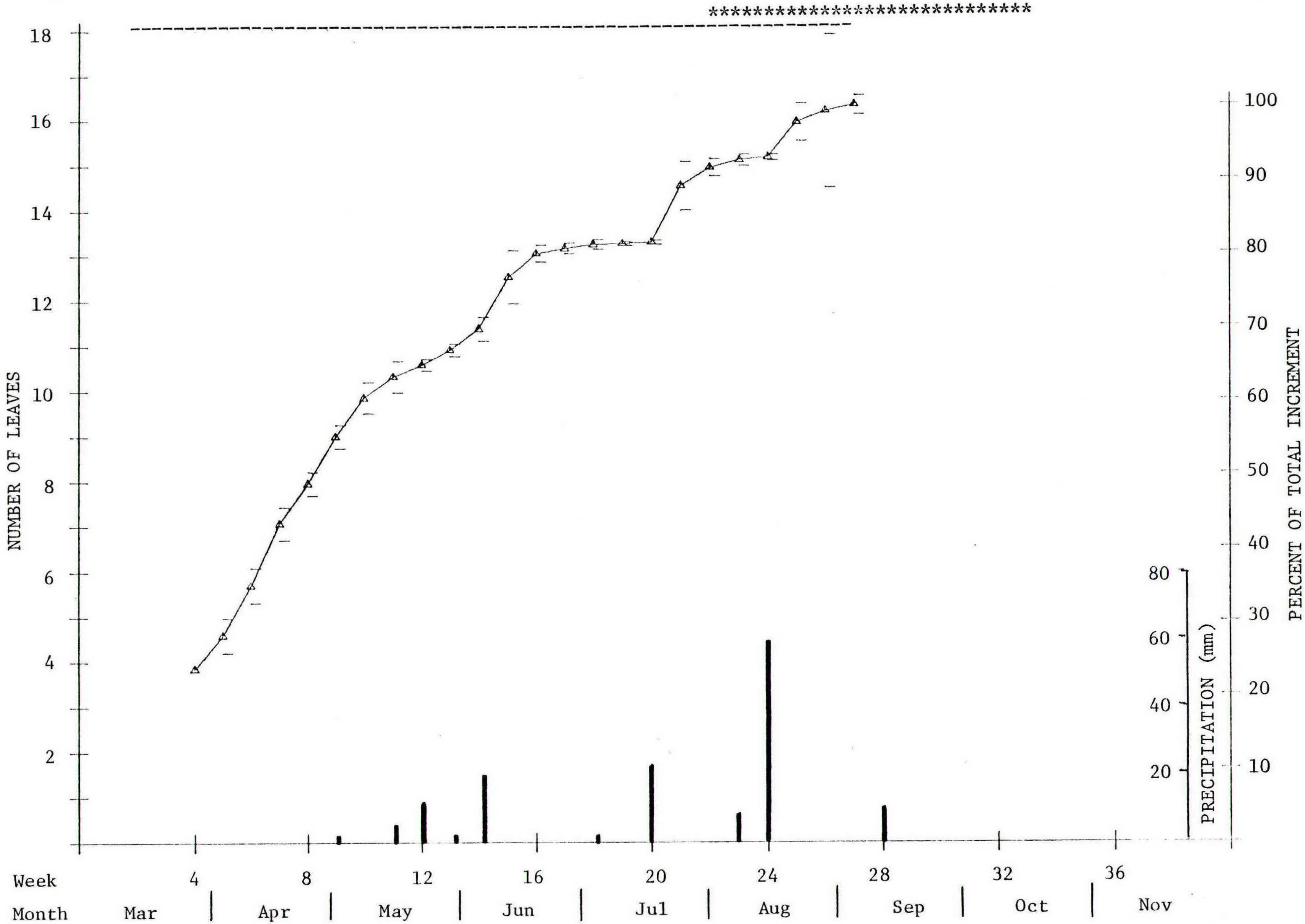

Figure 17. Accumulated weekly leaf increments for bush muhly at site D in 1979. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

In 1980 observations began on March 6. At this time new growth was found on only six of the 20 observation plants. Most of the plants initiated growth in week 2 or 3 but one plant did not began growing until week 5. Once started, branch growth was rapid, and 11 mm and 26 mm of rain received in weeks 6 and 9, respectively, caused accelerated growth rates (Fig. 18). After week 12 branch growth virtually ceased. Growth did not resume until after 17 mm of rain were received in week 24. Enough precipitation was received in weeks 26 and 28 to maintain a relatively high growth rate. No inrease in branch length occurred after week 32. Average length of branches was 14 cm less than in 1979.

Leaf development followed the pattern of branch length growth (Fig. 19). By week 14 there was an average of 10 leaves per branch. All of these leaves died and most were shed by week 23. When branch growth resumed in week 24 new leaves appeared, often on small branchlets of the original branch. By week 30 there was an average of 8.6 new leaves per branch. The plants produced two distinct and separate groups of leaves during the season.

Inflorescences did not appear until week 28. They were small in both size and number per plant. Shedding of seed was not complete until week 38 (November 22).

Bush muhly is perhaps one of the most difficult plants to sample for biomass and particularly for biomass increment for a season. Typically, bush muhly appears as a large rounded "bush". This "bush" is, in fact, made up of many individually rooted plants. Biomass increment for a season consists of branch and leaf development on the older culms and the development of new seedlings which germinate around the periphery of the "bush".

On September 19, 1979, 10 bush muhly "bushes" or clumps were harvested. From one of these, 20 individually rooted plants were separated. The 20 plants

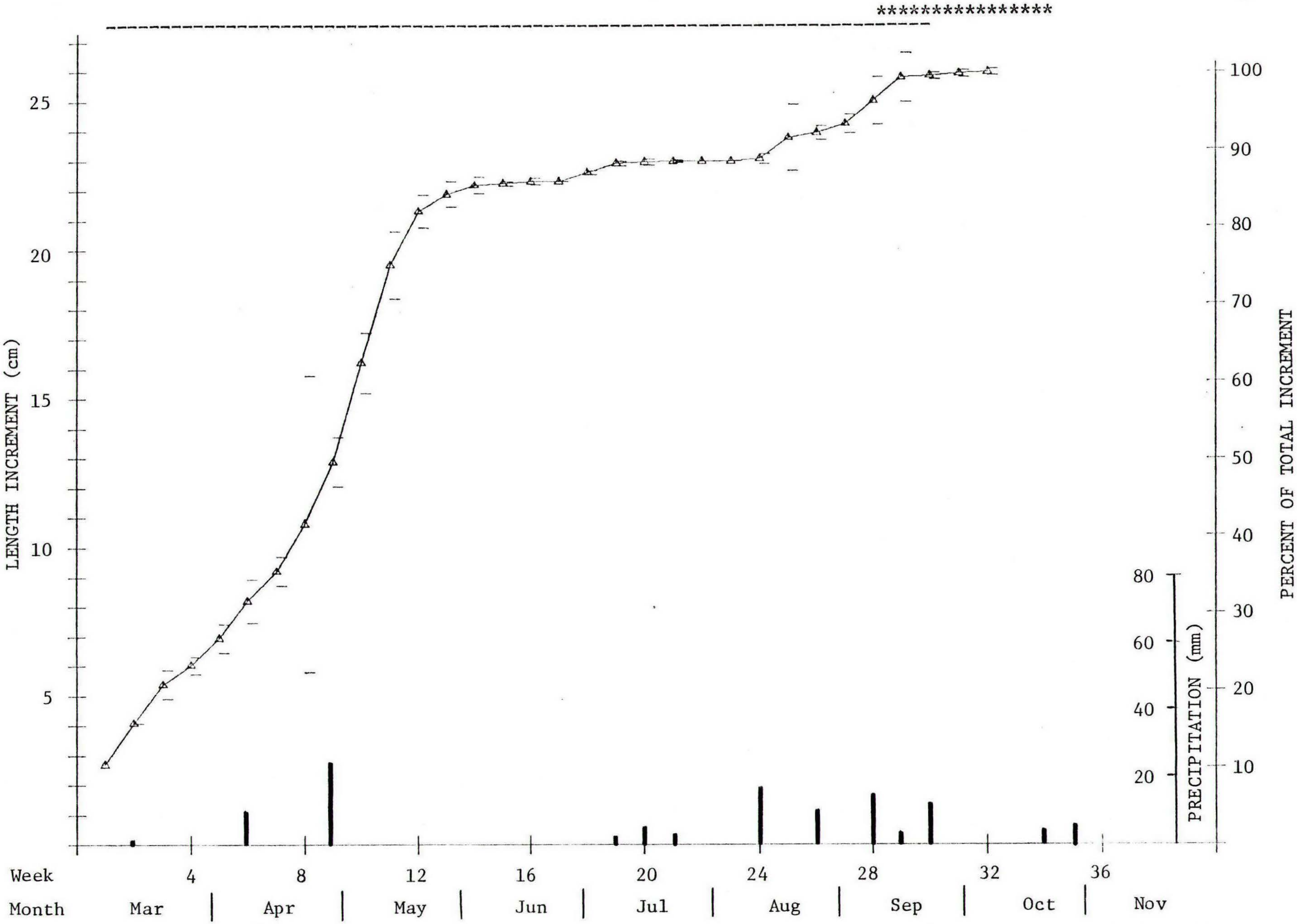

Figure 18. Accumulated weekly length increments for bush muhly culms at site D in 1980. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

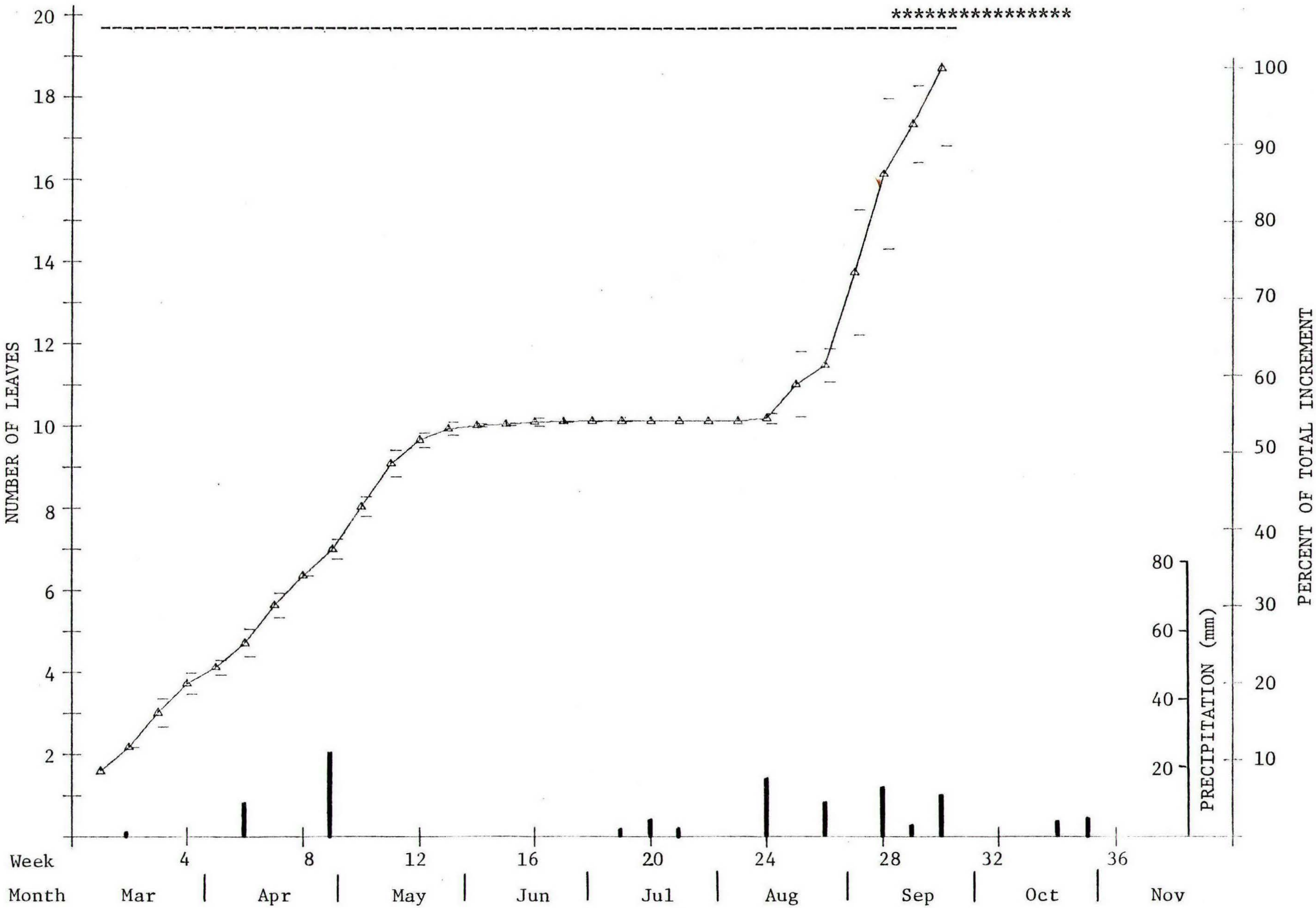

Figure 19. Accumulated weekly leaf increments for bush muhly at site D in 1980. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

were separated into current growth, old live culms and dead culms. A large subsample (1/8 to 1/4 of total material of each of the 10 bushes was also separated into the three components named above.

The "bushes" ranged in height from 52-70 cm and their diameters ranged from 75-150 cm. Current growth constituted 24-65% of the total weight. Old live culms contributed from 32 to 71% of the total weight. The variation in component weights was even greater for the 20 individual plants. Current growth ranged from 7-42% of total weight and old live culms ranged from 39-74% of the total weight.

Dimensional analyses using cylinder volume ($\pi r^2 h$) one half of a sphere ($1/2 \pi d^3$) and the upper half spheroid ($4/3 \pi r^2 h$) were performed using volumes as independent variables and total and current growth weights as dependent variables. Coefficients of determination (R^2) for total weight were .63, .53 and .63 for cylinder volume, 1/2 sphere volume and spheroid volume, respectively. Coefficients of determinations (R^2) for current growth weight were .61, .63 and .62 for cylinder volume, 1/2 sphere volume and spheroid volume, respectively. Since cylinder volume is easiest to calculate it is probably the best to use although none of the volumes can account for a very high percentage of the variation in weight.

Collections of about 100 bush muhly current season culm branches were made on March 2, June 6, July 2, and November 14, 1980. The number of leaves, length and oven-dry weight were determined for each individual branch. The culms were divided into reproductive (with inflorescence) and vegetative groups and the vegetative culms sorted into 4 cm length classes (Table VII). Linear regression analyses were used to determine the relationships between culm length, number of leaves and culm weighs. The midpoint of the length classes, the mean length of the reproductive class and number of leaves were used as the

Table VII Average culm weights and average number of leaves per culm for vegetative bush muhly culms in 4 cm length classes and a reproductive culm class (inflorescence developing or present).

Length class > cm < cm	N	Number of leaves $\bar{x} \pm$ SE	Weight in grams $\bar{x} \pm$ SE
0 - 4	70	2.6 ± .28	.003 ± .001
4 - 8	67	3.5 ± .11	.007 ± .0004
8 - 12	48	5.0 ± .16	.016 ± .0008
12 - 16	28	5.6 ± .17	.025 ± .0010
16 - 20	22	7.0 ± .39	.039 ± .0015
20 - 24	20 (17)1/	6.6 ± .48	.060 ± .0043
24 - 28	19 (18)	5.4 ± .84	.075 ± .0031
28 - 32	18 (15)	6.4 ± 1.06	.095 ± .0041
32 - 36	11 (6)	5.0 ± 2.27	.122 ± .0153
36 - 40	4	7.1 ± 2.38	.113 ± .0099
40 - 44	1	10. 9	.142
52 - 56	1	13. 1	.214
Reproductive class Mean length = 33.4 cm	88	1/	.209 ± .0213

1/ Number in parenthesis is the number of culms used in determining average number of leaves. Extensive leaf shedding prevented counts of leaves on some vegetative and all reproductive culms.

independent variables while mean culm weights were the dependent variables. The coefficient of determination (R^2) for weight of vegetative culms only with length was .98. When reproductive culms were included in the analysis the R^2 value was .84. The R^2 for weight of all culms with number of leaves was .73. Further examination of the length-weight relationships without class grouping is needed.

The indicated strong correlation of length with weight would be useful if a quick method of determining average current branch length could be devised. As mentioned in connection with plains bristlegrass, the length-weight relationship could be the basis for a PAF but it would apply only to the season in which it was determined.

Tobosa (Hilaria mutica)

Tobosa was first examined on March 29, 1979 (week 4). The culms averaged 5.4 cm in height and had an average of 3.8 leaves. The culms increased in height rapidly until week 10 when the growth rate declined sharply (Fig 20). A high-intensity rainstorm in week 14 (19.7 mm) had no apparent effect on culm growth rates. The 23 mm of precipitation occurring in week 20 caused an increase in growth rate in weeks 21 and 22. In week 24, 60 mm of precipitation were received and weeks 25 through 28 had the fastest rate of culm elongation of the season. Culm growth ceased in week 30 (September 25). Leaf development followed the culm elongation pattern and ended at the same time (Fig. 21).

The first inflorescences appeared on the tobosa plants in week 7 (April 19) and this set of reproductive culms had matured by week 19. Following the heavy rains in week 24 many culms began to produce inflorescences in week 26. These inflorescences had matured and shed their seed by week 37.

The growth of tobosa in 1980 was similar to 1979 but the division into two growing periods was much more sharply defined. When first examined on March 13, 1980 the culms averaged 6.7 cm in height and had an average of 3 leaves. By week 12 the culms had completed 77% of their total seasons growth (Fig. 22). At week 12 in 1979 only 38% of the total seasons growth had been completed.

There were only minor increases in culm height from week 13 to week 26. The 14 mm of precipitation received in week 27 resulted in an increased growth rate. No increase in culm height occurred after week 33. Leaf development followed the pattern of culm elongation very closely (Fig. 23). In 1980 the average culm length was 13 cm less than in 1979 and the average number of leaves per culm was 3.3 less in 1980 than in 1979.

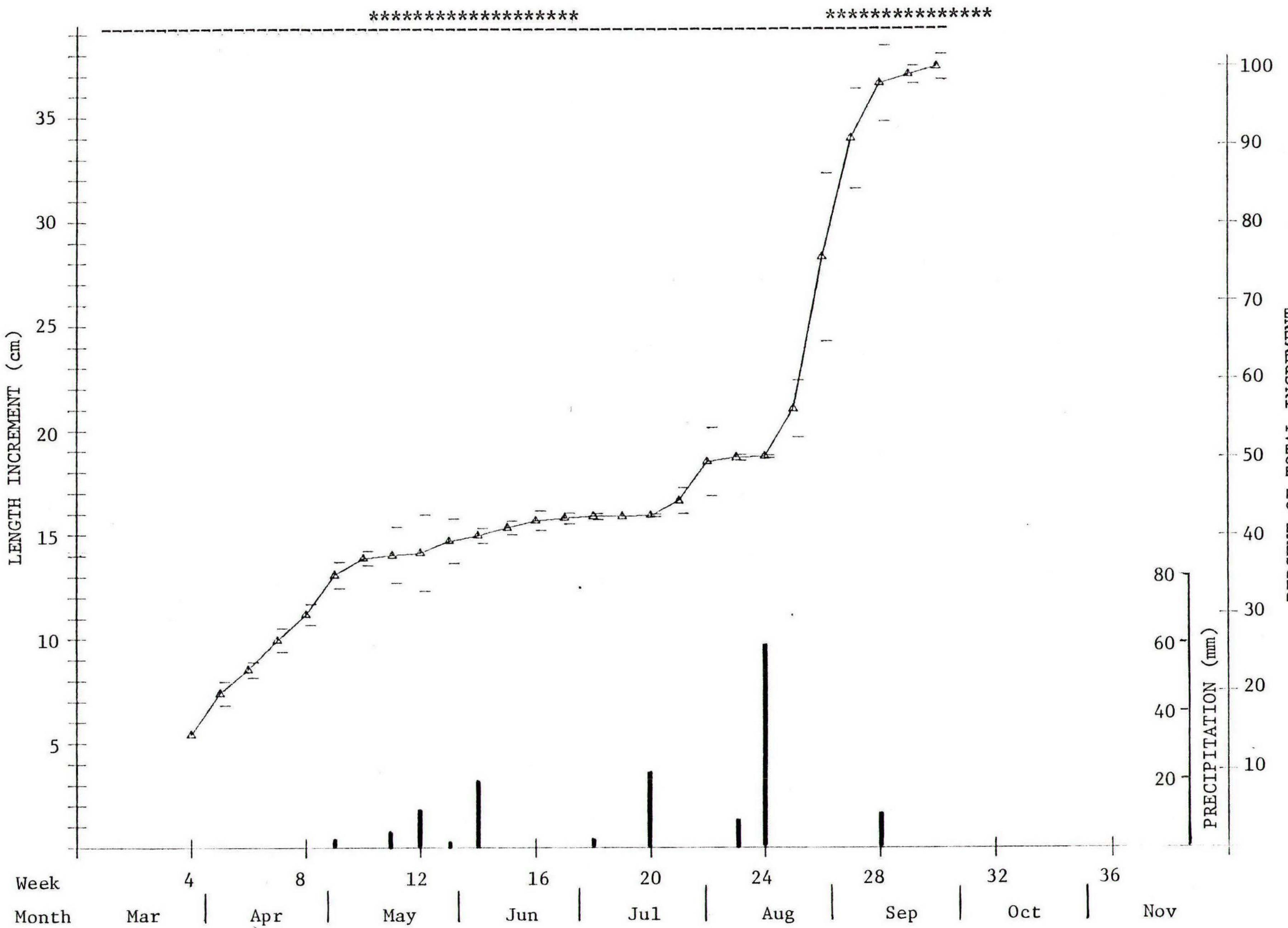

Figure 20. Accumulated weekly length increments for tobosa culms at site D in 1979. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

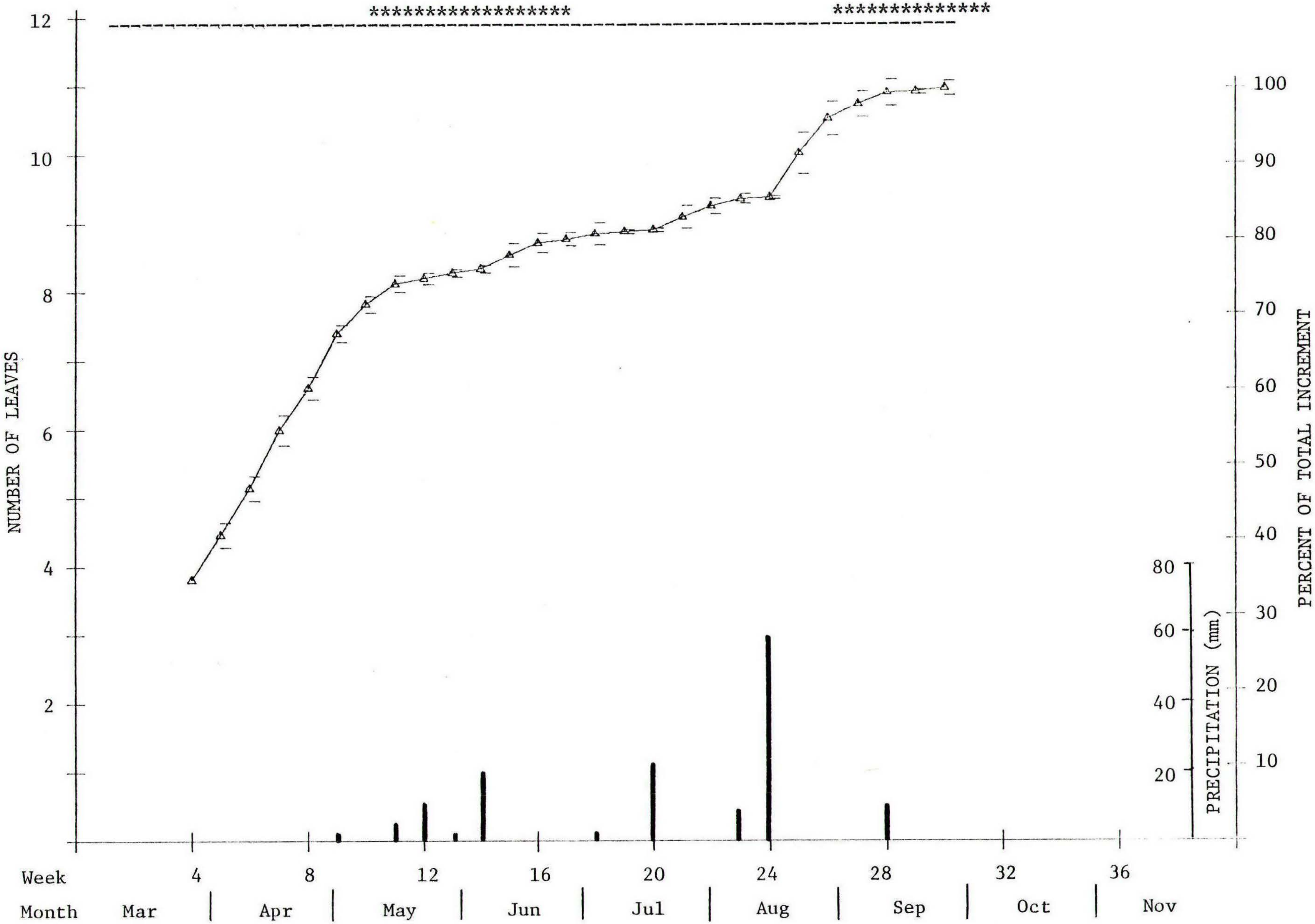

Figure 21. Accumulated weekly leaf increments for tobosa at site D in 1979. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

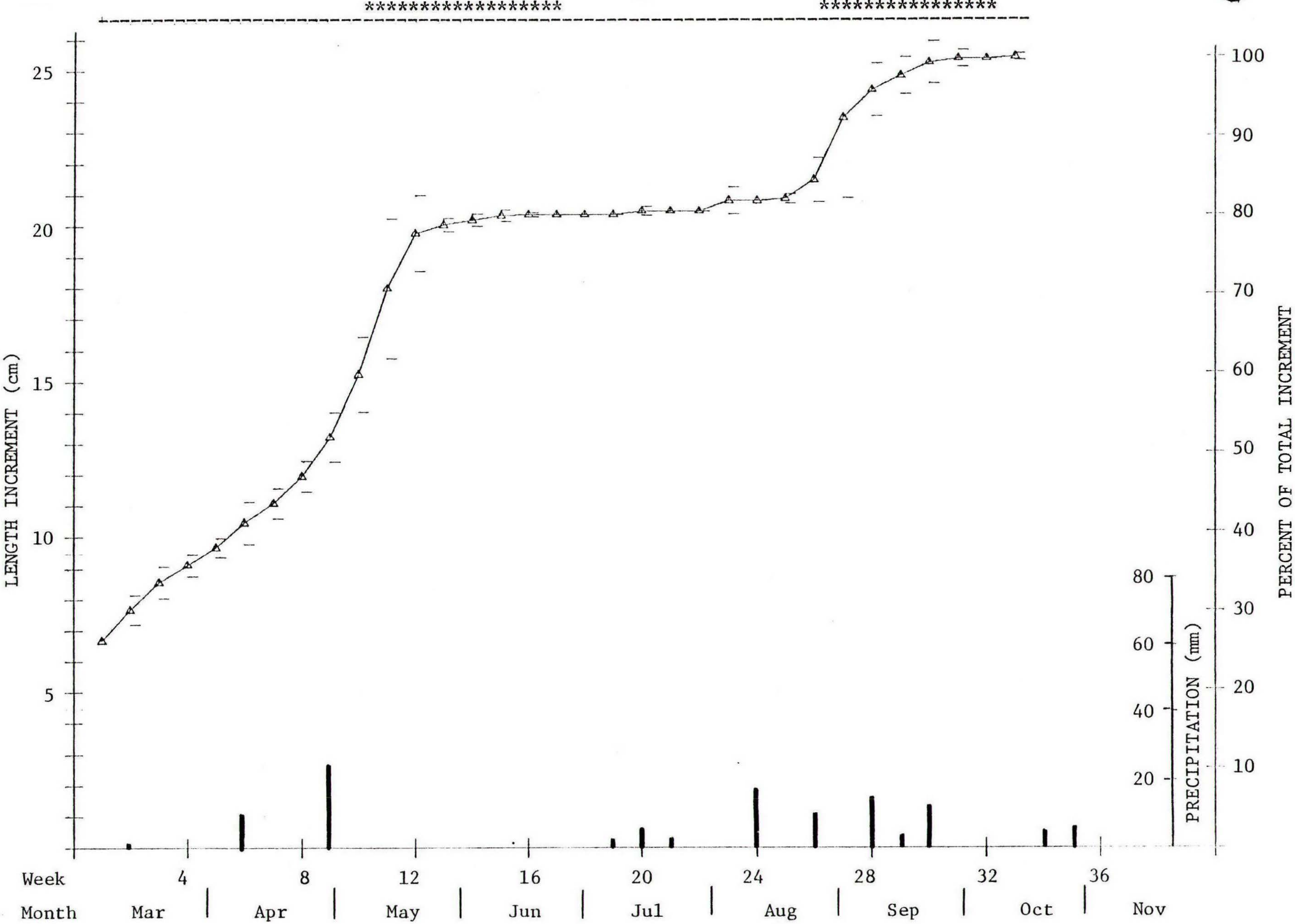

Figure 22. Accumulated weekly length increments for tobosa culms at site D in 1980. The dashes above and below the line denote 95% conficence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

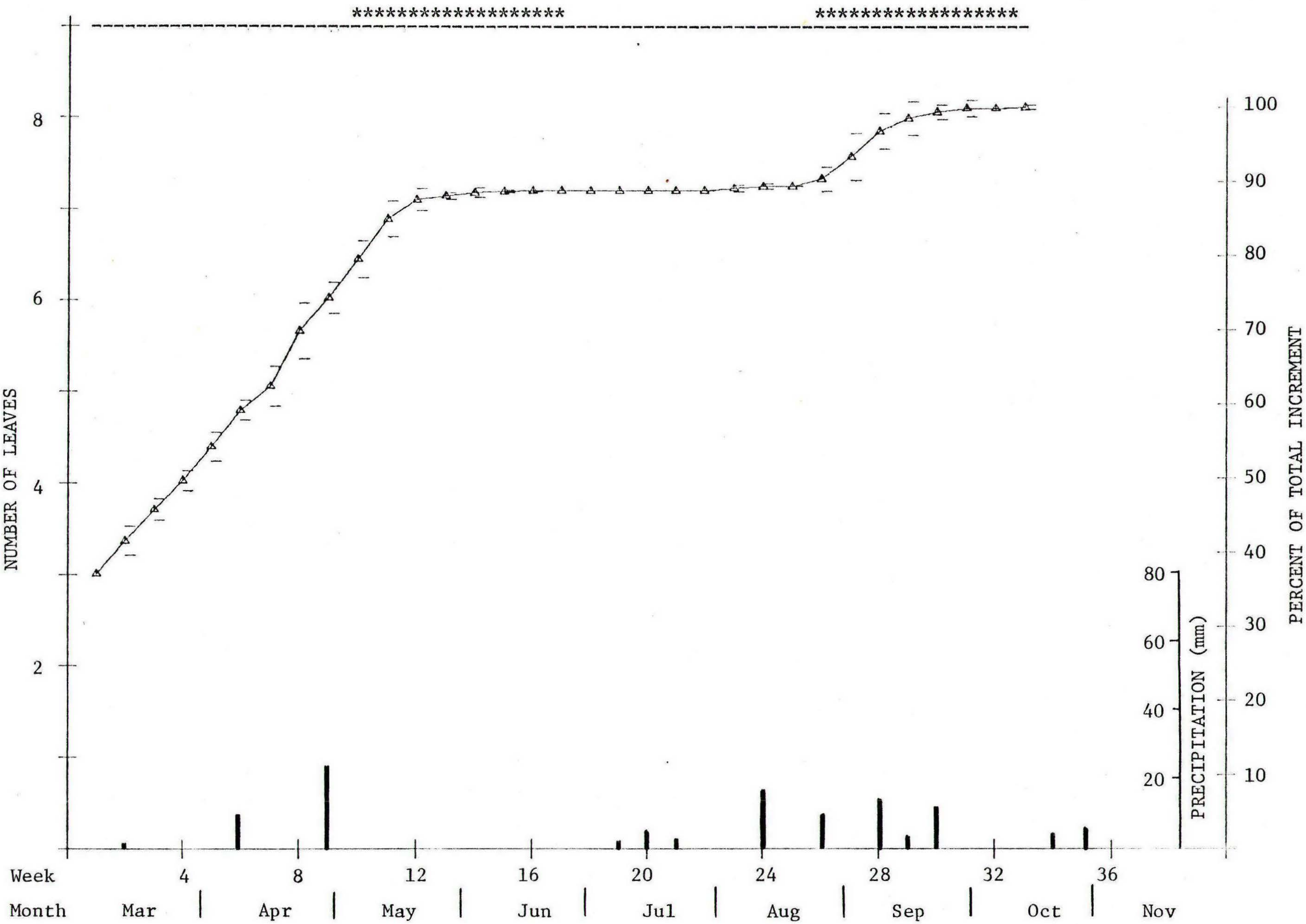

Figure 23. Accumulated weekly leaf increments for tobosa at site D in 1980. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

Inflorescences first appeared in week 10 and these had matured by week 22. A second group of culms produced inflorescences in weeks 26 through 28. The seeds had matured and been shed by week 36. The number of culms which produced inflorescences was small in comparison to 1979.

Tobosa plants were harvested on September 19, 1979. Fifty plants, perhaps better described as 50 discrete basal areas, were clipped and current growth separated from standing dead material. Average height of the plants was 55 cm and the averge basal area 25.6 cm^2. Average weight of current growth per cm^2 of basal area was .42 g with a range of .22 g to 1.10 g. Linear regression was used to examine the relationships between height, basal area, volume (basal area X height) and current growth weight and total weight of standing biomass. The coefficients of determination (R^2) for weight of current growth by height, basal area and volume were .33, .70 and .77, respectively. The R^2 values for total weight by height, basal area and volume were .38, .67 and .74, respectively. Since volume can account for more of the variabiliby in tobosa biomass it is the best parameter to use if non-destructive sampling is necessary.

On March 20, 1979, 150 tobosa culms were collected. About 100 culms were collected on May 8, June 2, and November 16. After determining length, number of leaves and weight of each culm they were separated into reproductive and vegetative groups. The vegetative group was further segregated into 4 cm height groups (Table VIII).

The mid-point of the length classes and number of leaves were used as independent variables in linear regression analyses to determine their relationships with the dependent variable, culm class weights. The coefficient of

determination (R^2) for vegetative culms weights only by length was .98. When reproductive culms were included in the analysis the R^2 value was .96. The R^2 for culm weights and leaf number was .86.

Even though a good relationship exists between culm length and culm weight it would be very difficult to establish a PAF for tobosa. The period of purely vegetative growth is very short. The early production of inflorescences appears to be characteristic of tobosa and means that the plants, or a portion of them, would have to be placed in a mature, reproductive phenophase long before the seasons vegetative phase was complete. As evidenced in 1979 and 1980, the percentage of culms which produce an inflorescence early, late, or not at all, is not constant from season to season.

Table VIII Average culm weights and average number of leaves per culm for vegetative tobosa culms in 4 cm length classes and a reproductive culm class (inflorescence developing or present).

Length Class $<$ cm $>$ cm	N	Number of leaves $\bar{x} \pm$ SE	Weight in grams $\bar{x} \pm$ SE
0 - 4	7	.8 $\pm$ .21	.014 $\pm$ .0041
4 - 8	66	1.7 $\pm$ .07	.020 $\pm$ .0011
8 - 12	85	2.6 $\pm$ .12	.050 $\pm$ .0035
12 - 16	72	3.5 $\pm$ .15	.098 $\pm$ .0069
16 - 20	40	4.2 $\pm$ .21	.114 $\pm$ .0074
20 - 24	37	5.0 $\pm$ .27	.218 $\pm$ .0187
24 - 28	22	4.2 $\pm$ .30	.222 $\pm$ .0156
28 - 32	33	5.6 $\pm$ .32	.300 $\pm$ .0145
32 - 36	3	5.5 $\pm$ .70	.353 $\pm$ .0451
Reproductive class Mean length = 44.3 cm	83	7.4 $\pm$ .22	.340 $\pm$ .0130

Black Grama (Bouteloua eriopoda)

Black grama plants have perennial culms that remain green year-round and from which new culms may originate as branches. However, in this study observations were confined to culms originating from the crown of the plants at ground level. Culms were tagged and measured on March 27, 1979. At this time the culms had an average length of 1.8 cm and had an average of 3.3 leaves per culm. The culms averaged 1.3 cm of length increase per week through week 10 and then the rate of growth declined (Fig. 24). Precipitation received in weeks 12-13 and 20-21 were followed by brief increases in rate of growth. The highest rates of increase in culm length for the season occurred in weeks 25-26 following the 39 mm of rainfall which was received in week 24. The culms ceased to increase in length at week 32 (November 9). Leaf development followed the pattern of culm elongation but no new leaves were developed after week 30 (Fig. 25). Inflorescences did not appear until week 27 (September 6) and all had matured by week 38. All current growth except the culm bases had dried by November 30.

When the black grama plants were examined on March 6, 1980 only one plant had new culms emerging. By the following week nine more plants had started growth. The remainder of the plants did not begin growth until week 3 or 4. The rate of increase in culm length was fairly low until week 7 but from week 8 through 12 the average weekly increment was 1.6 cm (Fig. 26). The culms grew very little from week 13 through week 22. The 19 mm of rain received in a single event in week 22 caused a sharp increase in culm growth rate. Another acceleration in growth rate followed the 41 mm of precipitation received in week 28. The very large average growth increments during weeks 29, 30, and 31 (> 4 cm week) are attributed to the development of seed stalks. Culm growth ceased following week 34 (November 22). Leaf development followed a pattern similar to culm development (Fig. 27).

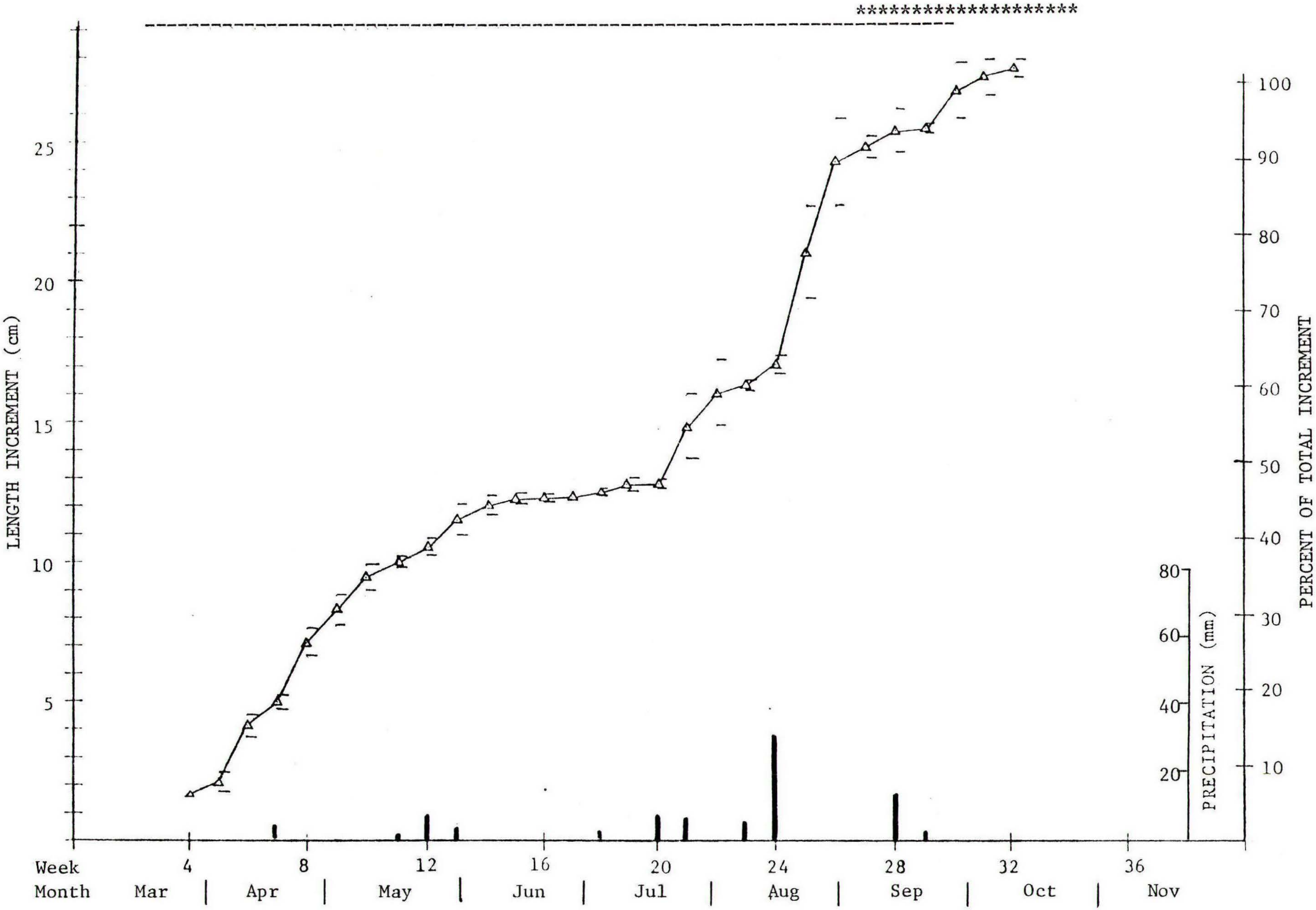

Figure 24. Accumulated weekly length increments for black grama culms at site C in 1979. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows the period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

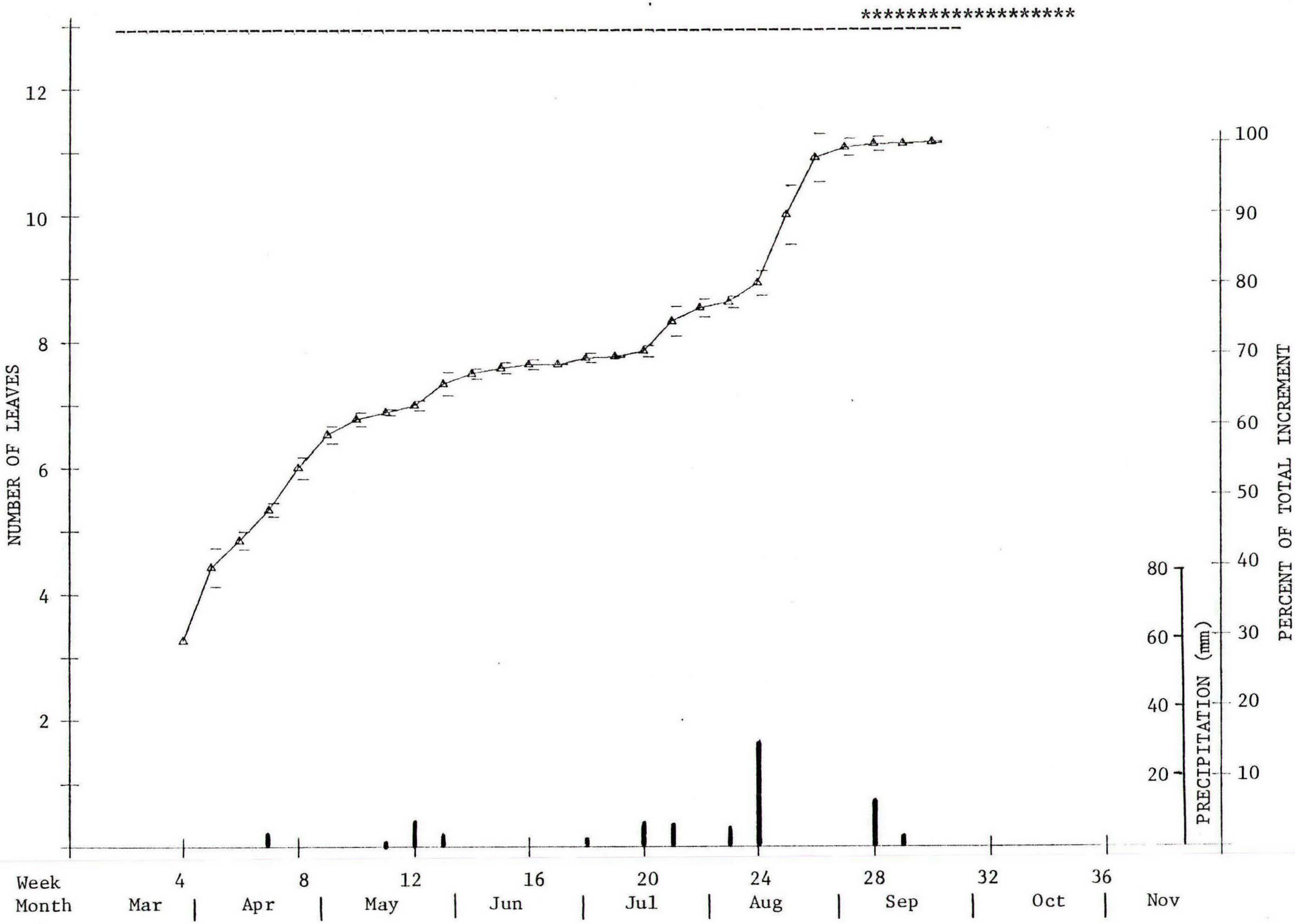

Figure 25. Accumulated weekly leaf increment for black grama at site C in 1979. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

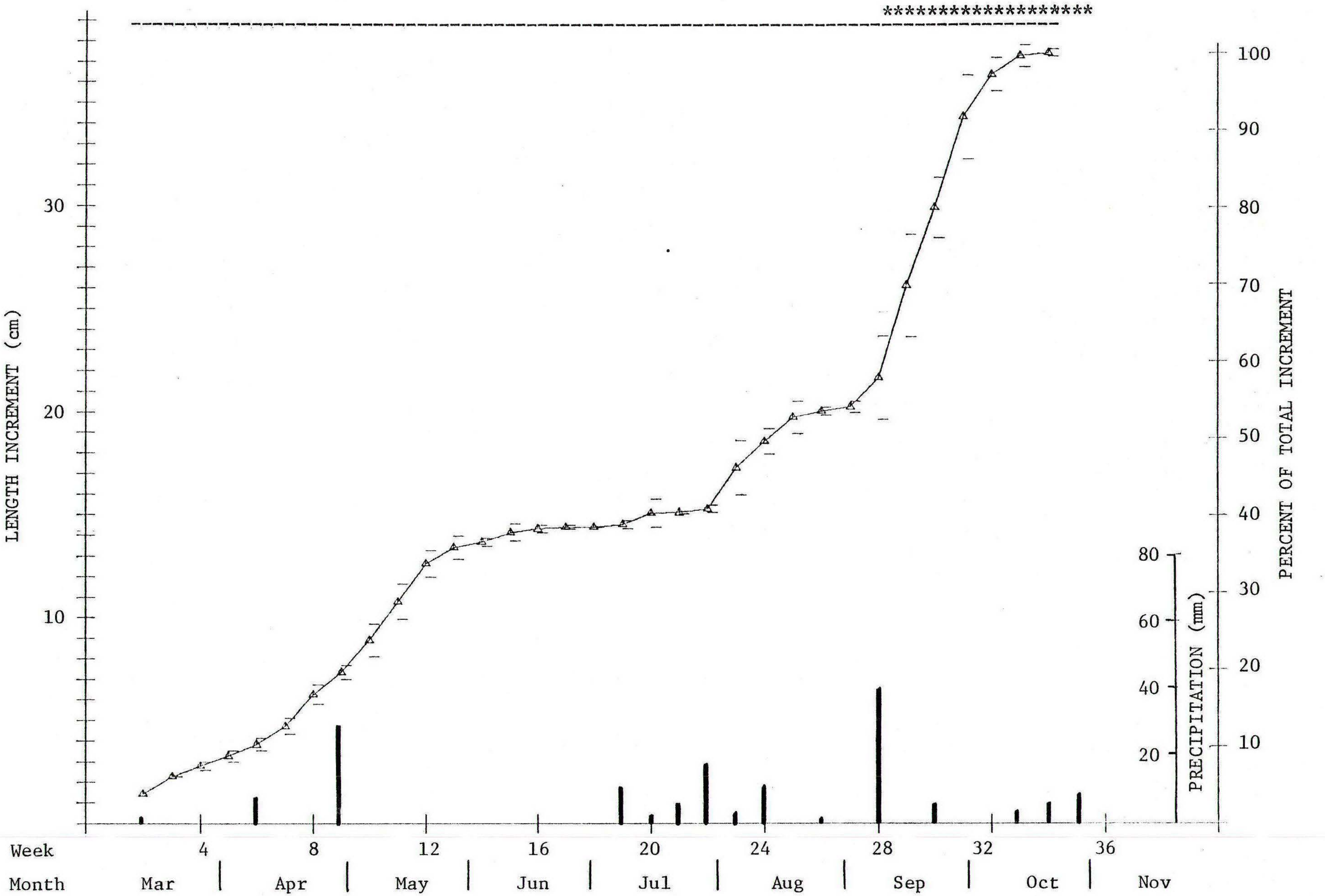

Figure 26. Accumulated weekly length increments for black grama culms at site C in 1980. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

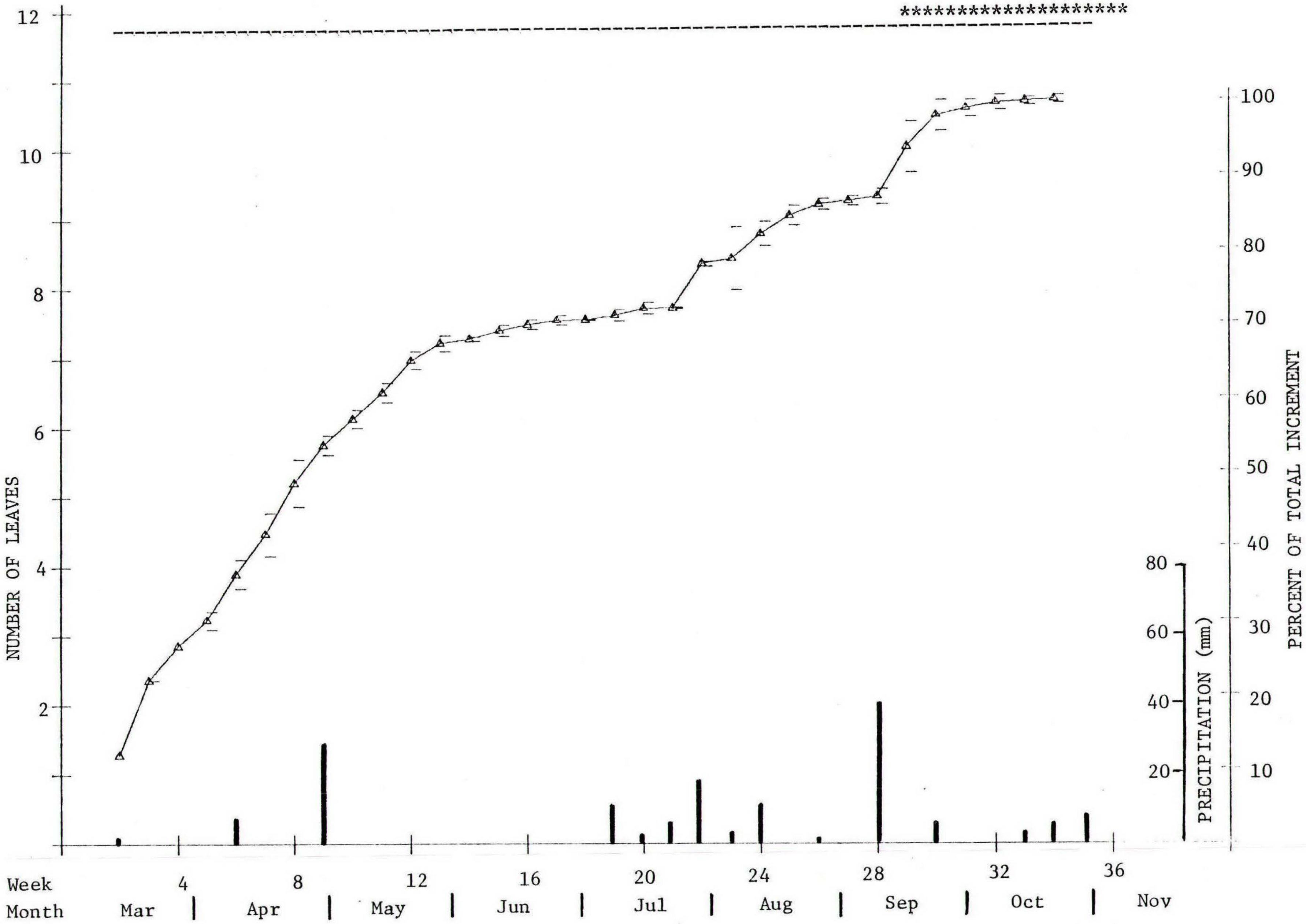

Figure 27. Accumulated weekly leaf increments for black grama at site C in 1980. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

Inflorescences appeared during week 28 and all had matured by week 39. The precipitation received during 1980 appeared timely in that a seed crop was produced. However, many black grama plants died during the season, evidently as a result of inadequate soil water.

Fifty black grama plants were harvested on September 20, 1979. Basal area, height, current growth weight (all live stems included, even though some of the stem weight was a carryover from the previous year) and standing dead material was determined for each plant. The harvested plants had an average height of 45 cm and an average basal area of 16.6 cm^2. Average weight of current growth and average total weight was .29 g and .55 g per cm^2 respectively. Linear regression analyses were performed using height, basal area and volume (basal area X height) as independent variables and weight as the dependent variable. Coefficients of determination (R^2) for weight of current growth and height, basal area and volume were .06, .68 and .75, respectively. Coefficients of determination (R^2) for total weight of standing biomass and basal area and volume were .67 and .71, respectively.

On December 12, 1980, 24 black grama plants were harvested. These plants had an average height of 48 cm and an average basal area of 25.8 cm^2. The average current growth per cm^2 was .17 g and the average total weight was .33 g per cm^2. Thus, in terms of biomass per cm^2, the 1980 season produced 41% less than the 1979 season. Admittedly, the samples are small and inadequate but the figures reflect a difference which was very apparent in the field.

On June 24, 1980, 25 actively growing black grama plants were clipped at a height of 10 cm. The portion removed was saved and separated into current growth and dead material. After observing the growth of the plants through the season the clipped individuals were harvested and separated into current growth and dead material. One of the clipped plants died. The yield of current

growth per cm^2 of basal area was .03 g at the end of the season. If the current growth removed at the June 24 clipping date is added to that harvested at the end of the season the current growth produced per cm^2 was .08 g or 53% less than that produced by the 24 plants not clipped early in the season. Inflorescences did not appear on the clipped plants until week 30, 2 weeks later than the first development of inflorescences in unclipped plants. Flowering was also two weeks later in the clipped plants. The clipped plants had an average height of 24 cm at the end of the season compared to the 48 cm average height of the unclipped plants.

Collections of individual black grama culms were made on May 5, June 2, August 16, and November 14, 1980. Length, number of leaves, and weight were determined for each culm. After dividing the culms into reproductive and vegetative groups, the vegetative culms were placed in 4 cm length groups (Table IX). Using the length class mid-points and number of leaves as independent variables and average class culm weights as dependent variables, linear regression analyses were performed. The coefficient of determination (R^2) for vegetative culm weight only and culm length was .98. When reproductive culms were added to the analysis the R^2 for culm weight with culm length was .94. The R^2 for culm weight and number of leaves was .96. It is apparent in Table IX that there is no clear boundary between weight of vegetative culms and that of reproductive culms. However, further analyses of the length-weight relationsips are needed.

The basic problem in deriving a PAF for black grama is the establishment of an adjustment when the plants pass from one phenophase to another. The overlap in vegetative and reproductive culm weights may pose insurmountable difficulties. The culm length-weight relationship does appear strong enough to permit setting season end weight as 100 percent of growth and using culm length

to proportion the total weight through the season. As mentioned before, this has practically no predictive value among seasons.

Table IX. Average culm weights and average number of leaves per culm for vegetative culms of black grama in 4 cm length classes and a reproductive culm class (inflorescence developing or present).

Length Class $>$ cm $<$ cm	N	Number of leaves $\bar{x} \pm SE$	Weight in grams $\bar{x} \pm SE$
0 - 4	5	2.8 ± .33	.012 ± .0022
4 - 8	53	3.0 ± .11	.021 ± .0013
8 - 12	63	3.6 ± .10	.041 ± .0017
12 - 16	35	4.2 ± .18	.061 ± .0025
16 - 20	32	4.8 ± .27	.088 ± .0036
20 - 24	36	5.6 ± .30	.126 ± .0057
24 - 28	20	7.1 ± .42	.174 ± .0083
28 - 32	22	6.9 ± .44	.216 ± .0093
32 - 36	8	8.3 ± .70	.249 ± .0205
36 - 40	12	9.6 ± .41	.279 ± .0207
40 - 44	6	10.2 ± 1.07	.329 ± .0291
44 - 48	4	10.5 ± .79	.461 ± .0254
48 - 52	4	10.2 ± .23	.420 ± .0447
52 - 68 1/	4	11.9 ± .70	.598 ± .0297
Reproductive class Mean length = 46.4 cm	95	7.1 ± .16	.198 ± .0110

1/ Height classes combined for simplicity.

Spike Dropseed (Sporobolus contractus)

Culms of spike dropseed were tagged and measured on March 22, 1979. Growth was well under way and the culms had an average length of 5.5 cm and an average of 1.8 leaves. A rapid rate of growth was maintained until week 14 (Fig. 28). In weeks 15 through 20 very little culm growth occurred. The 48 mm of rainfall received in week 20 was followed by an acceleration in culm growth in weeks 21-22. In week 24, 44 mm of precipitation ocurred and this was followed by a very rapid rate of culm extension in the three succeeding weeks. Rainfall events in weeks 28 and 29, 17 and 5 mm, respectively, evidently resulted in the accelerated growth rate in week 30. After the first few weeks of the season culm growth was apparently entirely dependent on rainfall events. No growth in culms was detected after week 33 (November 15). Leaf development closely followed the pattern established by culm growth and by week 29 there was an average of 8 leaves per culm (Fig. 29). Inflorescences began to develop in week 26, following the effective precipitation in week 24. Inflorescences continued to emerge until week 36. Most of the seed had been shed by week 39 (November 30).

When the spike dropseed plants were first examined on March 7, 1980, all had started growth. The culms averaged 4.4 cm in length and there was an average of 1.3 leaves per culm. The growth pattern in 1980 differed considerably from that exhibited in 1979. Growth in the early weeks was not as rapid as in 1979 and the period of relatively rapid growth terminated in week 11, three weeks earlier than in 1979 (Fig. 30). Apparently the soil water supplied by rainfall events of 12 and 36 mm in weeks 8 and 9, respectively, was quickly exhausted. Practically no culm growth occurred during weeks 14 through 23. Following a total of 24 mm of rainfall in weeks 23-24 the culms grew rapidly in weeks 25-26. After virtually ceasing to grow in weeks 27-28 the culms

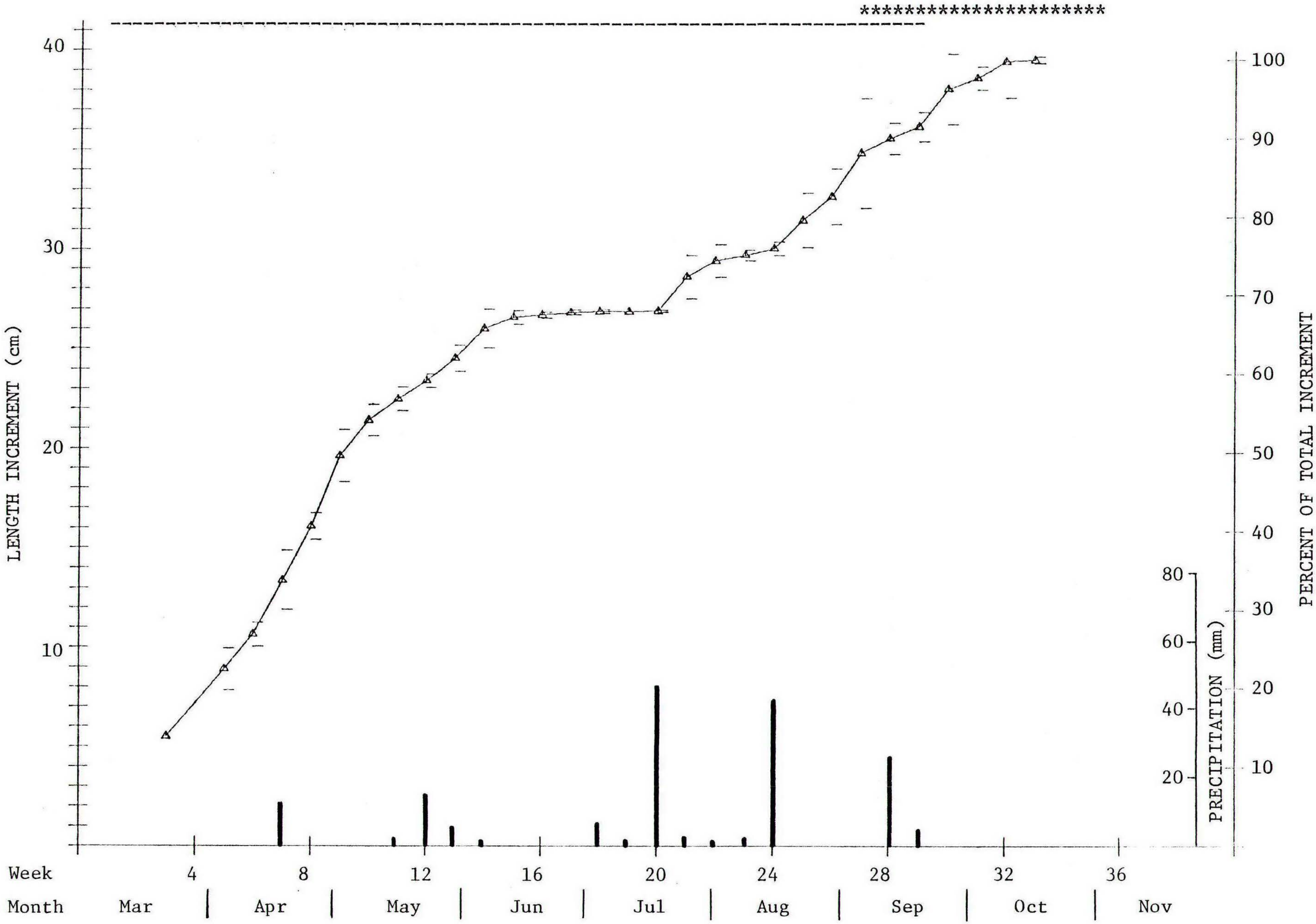

Figure 28. Accumulated weekly length increments for spike dropseed culms at site B in 1979. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

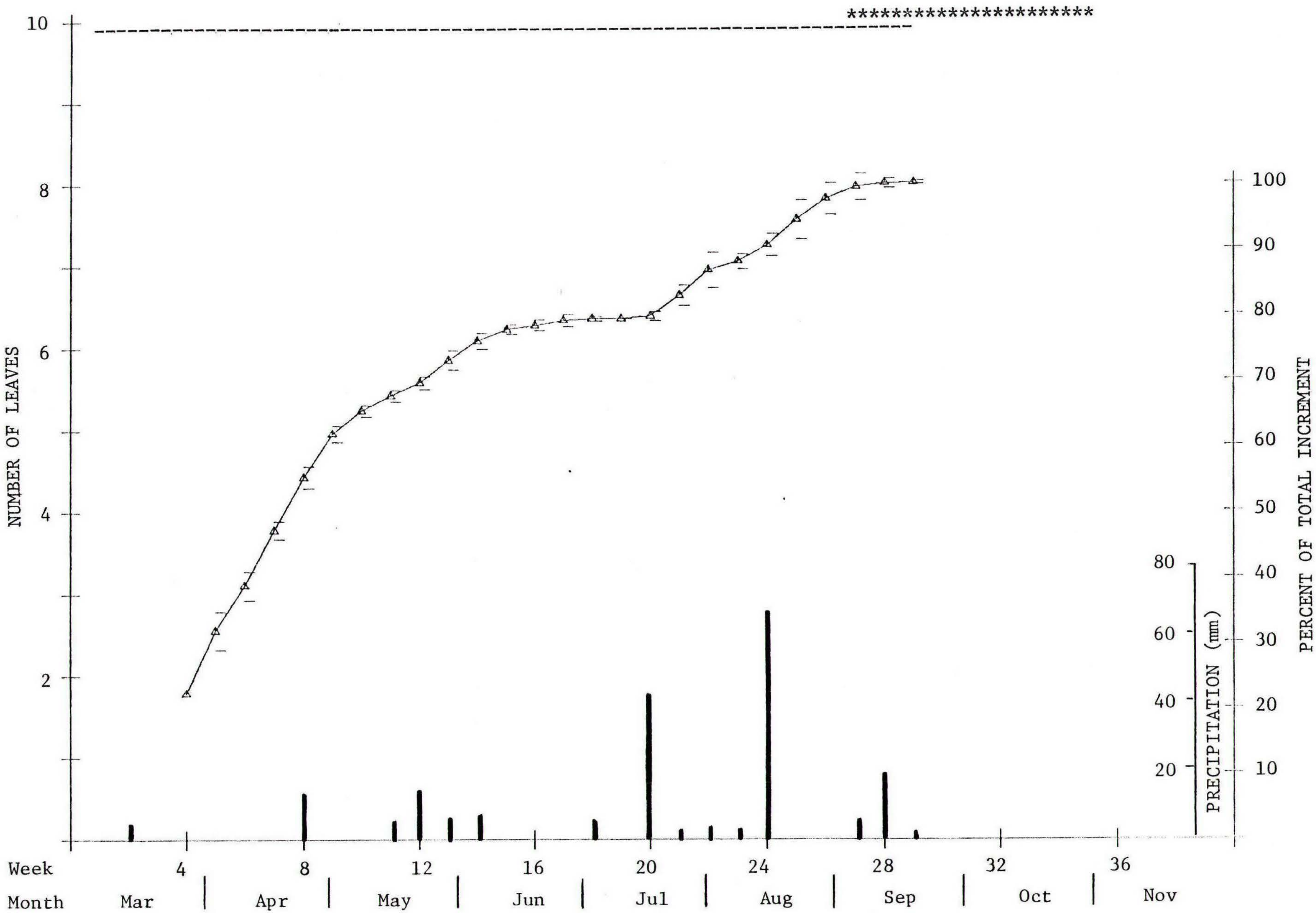

Figure 29. Accumulated weekly leaf increments for spike dropseed at site B in 1979. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

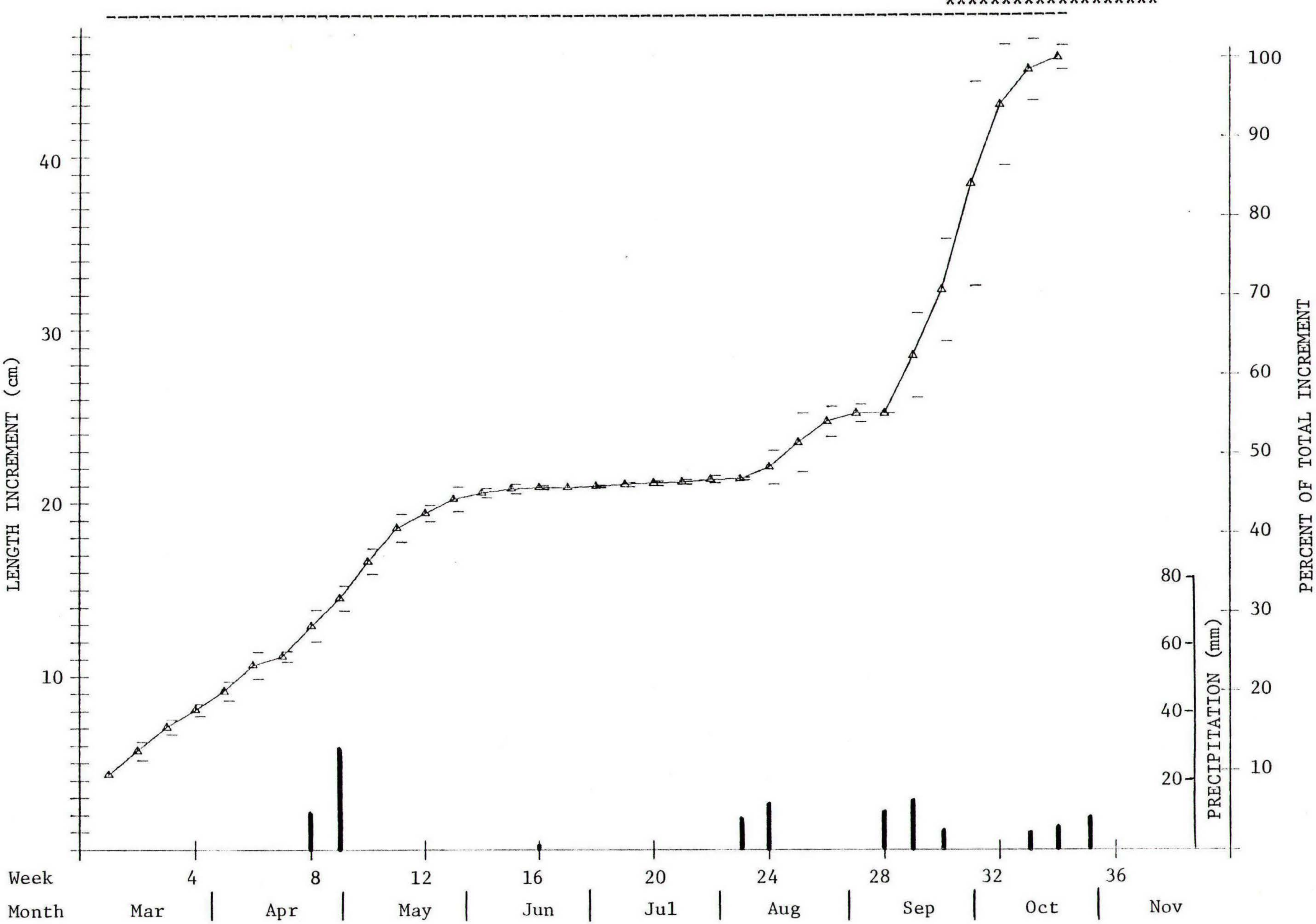

Figure 30. Accumulated weekly length increments for spike dropseed culms at site B in 1980. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

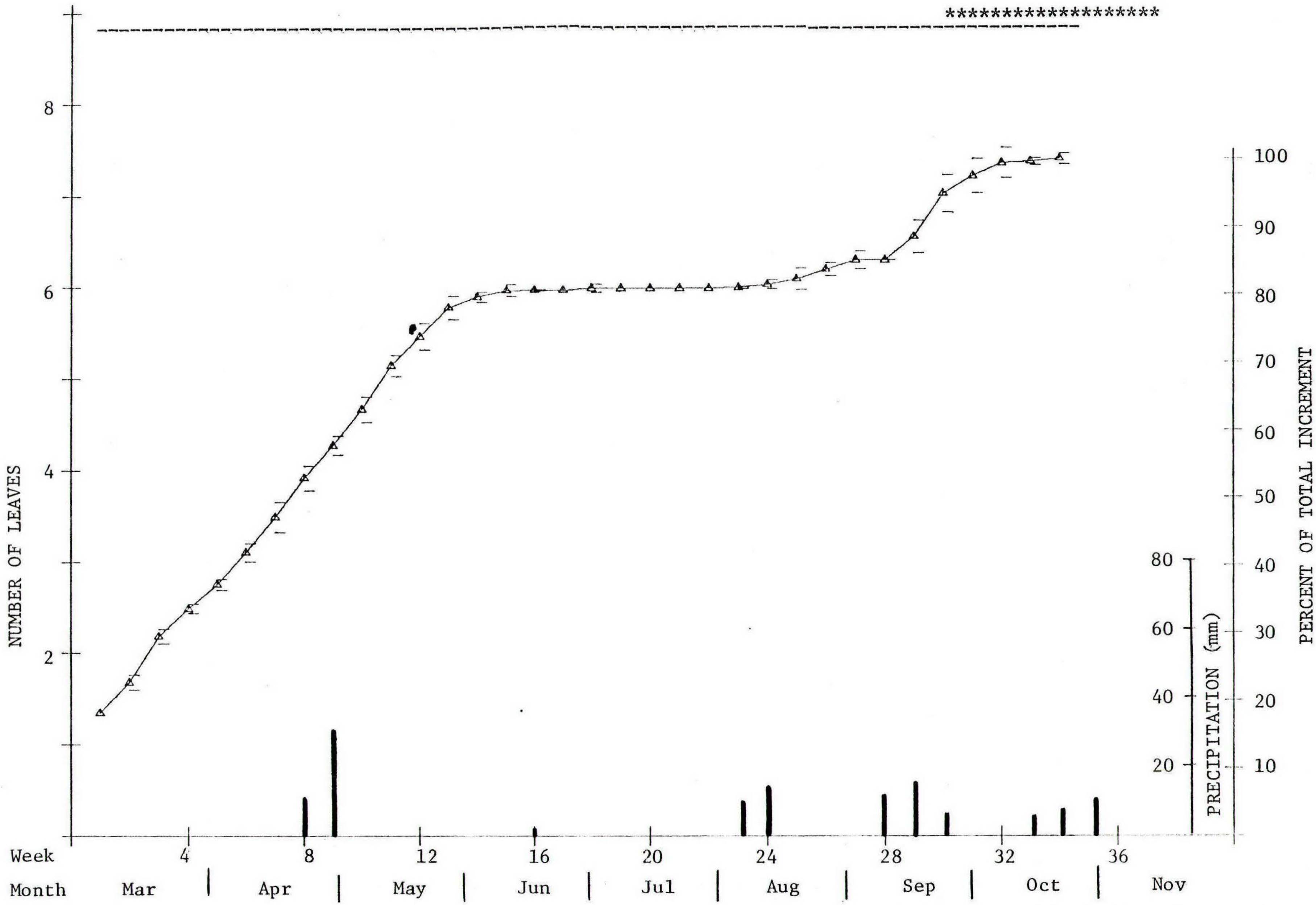

Figure 31. Accumulated weekly leaf increments for spike dropseed at site B in 1980. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

averaged 4 cm of growth per week from week 29 through 33. This final spurt of growth was triggered by the 34 mm of precipitation received in weeks 28 through 30. The extremely rapid rate of culm extension also reflects the emergence of inflorescences. Leaf development was concentrated in the early part of the season (Fig. 31). At week 11 there was an average of 5 leaves per culm. When leaf development ceased in week 34 there was an average of only 7 leaves per culm. Frequently, the first-formed leaves were partially or totally dry by the middle of the season. The first inflorescences developed in week 30, 4 weeks later than in 1979. Most inflorescences did not develop until weeks 36 and 37. Not all of the inflorescences, which were much less abundant than in 1979, produced seed. Development was not completed on some plants until week 40 (December 5).

Spike dropseed plants were harvested on April 4 and September 21, 1979 and on November 13, 1980. Height of current growth, basal area, weight of current growth and weight of standing dead material was determined for each plant. Statistics for each collection are presented in Table X. Volume (basal area X height) was able to account for more of the variation in weight than either height or basal area for all collections. The weight of current growth per cm^2 of basal area was .04 g, .64 g and .25 g for the April and September, 1979 and November, 1980 collections, respectively. Total weight per cm^2 of basal area was .26 g, .87 g and .51 g for the April, September and November collections, respectively. The relatively poor 1980 growing season is reflected in the weight of current growth per cm^2 which was 61% less in November, 1980 than in September, 1979.

On March 20, May 5, June 2, September 9, and November 14, 1980 collections of 100 or more spike dropseed culms were made. Length, numbers of leaves, and weight were determined for each culm. Reproductive culms were

Table X. Statistics for spike dropseed plants harvested during 1979 and 1980. Linear regression procedures were used to determine relationships between height, basal area and volume (basal area X height) as independent variables and weight of plant material as the dependent variable.

Date	N	Height of current growth ($\bar{x}$ cm $\pm$ SE)	Basal Area ($\bar{x}$ cm^2 $\pm$ SE)	Current growth weight ($\bar{x}$ g $\pm$ SE)	Total weight ($\bar{x}$ g $\pm$ SE)
March 27, 1979	20	19.5 $\pm$ .9	34.8 $\pm$ 5.2	1.43 $\pm$ .30	9.64 $\pm$ 2.23
September 21, 1979	20	110.2 $\pm$ 3.5	29.3 $\pm$ 3.4	16.42 $\pm$ 1.95	23.04 $\pm$ 3.01
November 13, 1980	25	78.4 $\pm$ 10.5	38.4 $\pm$ 5.6	7.24 $\pm$ .87	17.03 $\pm$ 2.00

	Coefficients of Determination (R^2)				
	Current growth weight			Total weight	
	Height	Basal area	Volume	Basal area	Volume
March 27, 1979	.54	.74	.82	.52	.65
September 21, 1979	.28	.60	.66	.65	.72
November 13, 1980	.09	.32	.40	.55	.60

segregated into one class and the vegetative culms were divided into 4 cm length classes (Table XI).

The length class mid-points and average length for the reproductive culm class and number of leaves were used as independent variables and culm weights as the dependent variables in linear regression analyses. The coefficient of determination (R^2) for culm weight with length and number of leaves was .94 and .87, respectively. Since culm length can account for 94% of the variability in average weight for culm height classes and there is a marked separation of weights between vegetative and reproductive culms the derivation of a PAF seems possible.

A culm length based PAF can be tested in relation to biomass. If we use the culm growth curve for 1979 we find an average culm height of 16 cm occurring in week 8 (same week as the May collection of plants). The culm length reached in week 8 is 41% of the average culm length at the end of the season. Yet, the May collection accounted for only 20% (weight per cm^2), or 13% (average weight per plant), of the current growth weights determined by the sampling in September. Even if it is assumed that biomass accumulates linearly over time and a PAF is established for 1979, any predictions made with the PAF would grossly overadjust the 1980 production because of the 61% difference in yield per cm^2 of basal area.

Table XI. Average culm weights and average number of leaves per culm for vegetative spike dropseed culms in 4 cm length classes and a reproductive culm class (infloresence developing or present).

Length Class < cm > cm	N	Number of Leaves $\bar{x} \pm SE$	Weigh in grams $\bar{x} \pm SE$
0 - 4	21	1.2 ± .12	.007 ± .0006
4 - 8	86	1.5 ± .06	.011 ± .0005
8 - 12	39	2.0 ± .09	.021 ± .0016
12 - 16	23	2.7 ± .14	.045 ± .0041
16 - 20	37	2.9 ± .11	.064 ± .0047
20 - 24	40	3.3 ± .15	.096 ± .0055
24 - 28	42	4.4 ± .52	.153 ± .0103
28 - 32	56	4.8 ± .21	.264 ± .0188
32 - 36	38	5.2 ± .28	.327 ± .0239
36 - 40	38	5.5 ± .22	.414 ± .0249
40 - 44	14	6.3 ± .40	.552 ± .0511
44 - 48	6	5.0 ± .32	.388 ± .0522
48 - 52	3	4.8 ± .46	.472 ± .0787
Reproductive class Mean length = 83.4 cm	100	8.4 ± .16	1.116 ± .0479

Mesa Dropseed (*Sporobolus Flexuosus*)

Two groups of mesa dropseed plants were observed in both 1979 and 1980. One group was located at site A and the other group at site B. Culms on the plants at site A were tagged and measured on March 27, 1979. The culms averaged 6.5 cm in height and had an average of 3.3 leaves per culm. A rapid rate of growth was maintained through week 15 (Fig. 32). The greatest weekly increment of 4.7 cm occurred in week 9 following the 14 mm of precipitation received in week 8. Culm growth rates were minimal from week 16-20. The 43 mm of precipitation received in week 20 caused a sharp increase in growth rate. In week 24, 68 mm of precipitation were received and another sharp increase in the rate of culm growth followed. In week 28 the weekly increment in culm growth was 8.7 cm, highest of the season. The culms ceased to increase in height after week 31 (November 2). Leaf development followed the same pattern as culm growth (Fig. 33). When leaf development ceased in week 32 there were an average of 10 leaves per culm. Most of the leaves (70%) were developed by week 14. Usually the first 2 to 3 leaves formed had dried by the middle of the season. Inflorescences began to appear (boot stages) in week 21 (July 24). However, inflorescence development was most prevalent during week 25, following the effective precipitation occurring in week 24. Shedding of seed occurred primarily in week 30 but some inflorescences did not mature until week 37. By week 38 the plants were dry and dormant.

At site B, located about 3 miles from site A, mesa dropseed culms displayed a growth pattern entirely different from that of the culms at site A (Fig. 34). The culms tagged and mesured on March 22 had an average height of 4.6 cm and an average of 2.8 leaves per culm. Thus, the site B culms were longer than the site A culms at the beginning of the season. Through week 15 culm growth was nearly equal at the two sites. Like culms at site A, those at

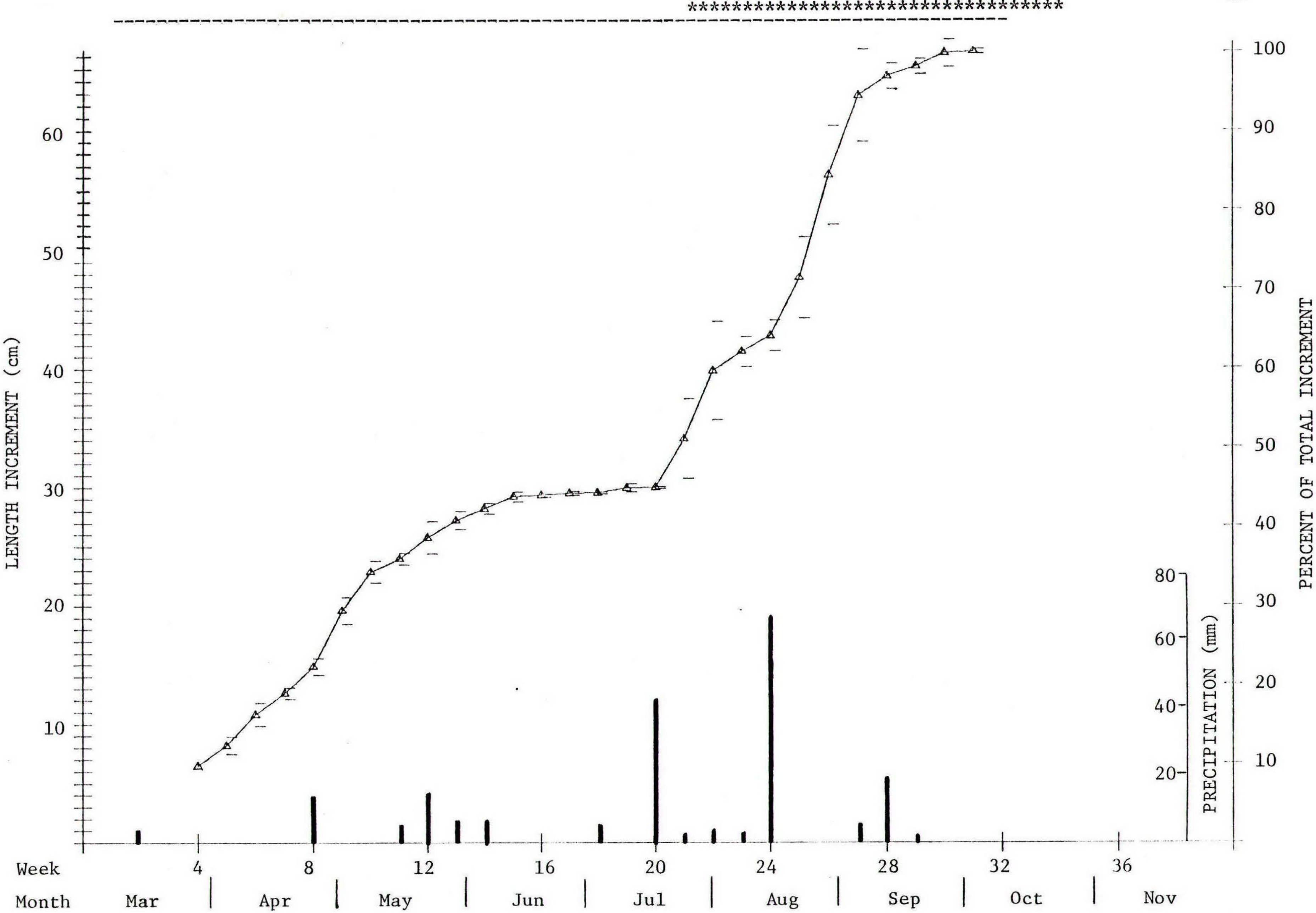

Figure 32. Accumulated weekly length increments for mesa dropseed culms at site A in 1979. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

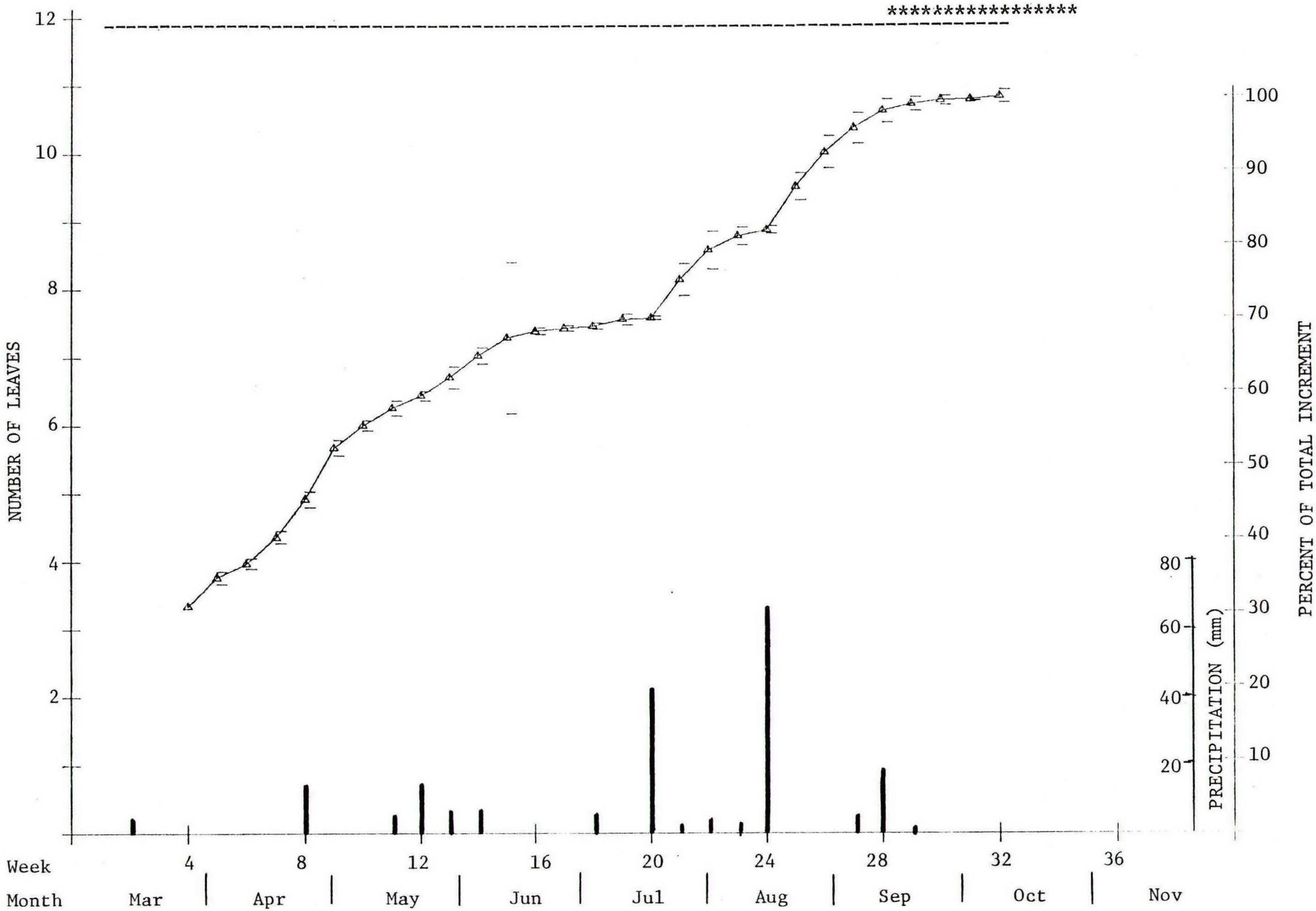

Figure 33. Accumulated weekly leaf increments for mesa dropseed at site A in 1979. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

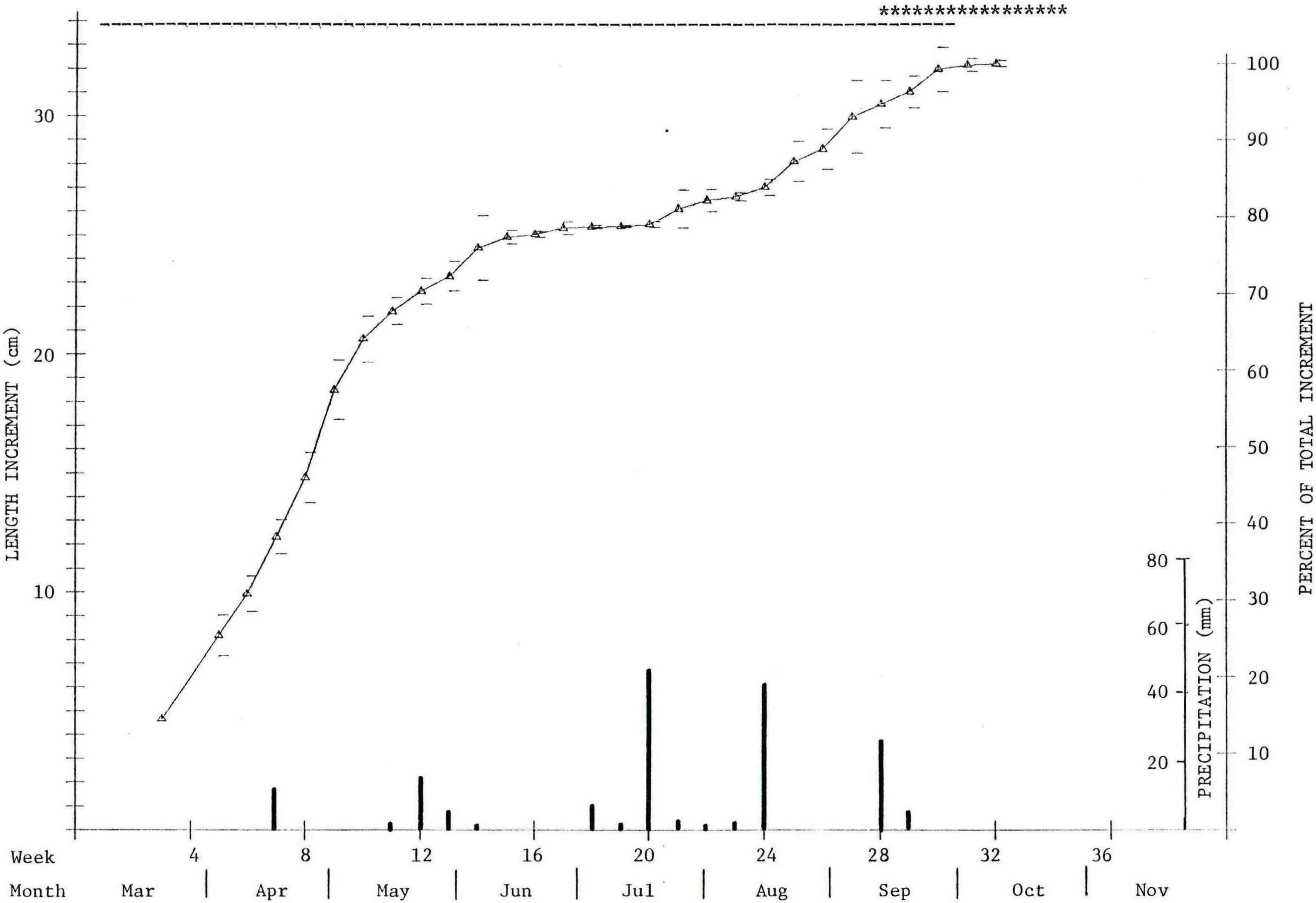

Figure 34. Accumulated weekly length increments for mesa dropseed culms at site B in 1979. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

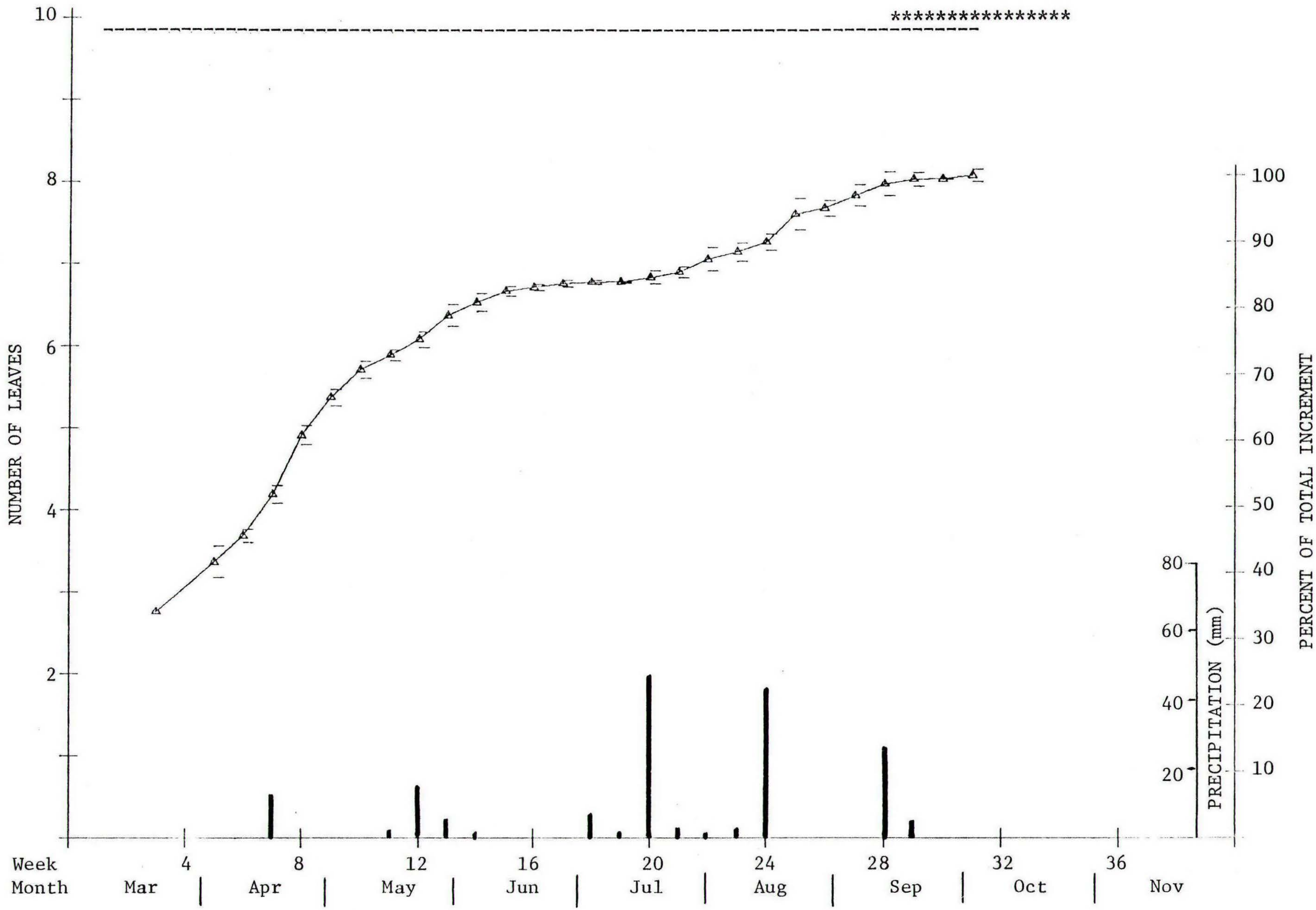

Figure 35. Accumulated weekly leaf increments for mesa dropseed at site B in 1979. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

site B made minimal growth in weeks 16 through 20. The amount of rainfall received in week 24 at site B was slightly greater, 48 mm vs. 43 mm, than that received at site A. However, culms at site B showed only a moderate increase in growth rate following the precipitation events. Probably this low response was due to the competition for soil water by the very dense stand of annuals present on site B. Site A did not have large numbers of annual plants. Site B received only 44 mm of precipitation in week 24, as compared to the 68 mm received at site A. The culms at site B showed an increase in growth rate following the precipitation but it was much less than the growth rates exhibited by culms at site A (20.2 cm at site A and 3.0 cm at site B in weeks 25 through 27). When the culms at site B ceased growth in week 32 their average length was 35 cm less than the culms at site A. Leaf development of mesa dropseed at site B followed the culm growth pattern (Fig. 35). In week 32 there was an average of 8 leaves per culm, two less than on the culms at site A.

Inflorescence development did not begin until week 28 at site B. The number of inflorescences produced was small in comparison to the number produced at site A (4 out of the 20 culms at site B vs. 17 out of the 20 culms at site A). Seeds had matured and been shed by week 35 and the plants were dry and dormant at week 39.

In 1980 the mesa dropseed plants at site A and B were first examined on March 7. All of the plants had developing culms at this time. At site A the culms had an average length of 4 cm and the average number of leaves per culm was 1.8. At site B the average culm length was 3.5 cm and the average number of leaves per culm was 1.7. The pattern of culm elongation was quite similar at sites A and B throughout the season (Figs. 36 and 37). Leaf development was also very similar (Fig. 38 and 39).

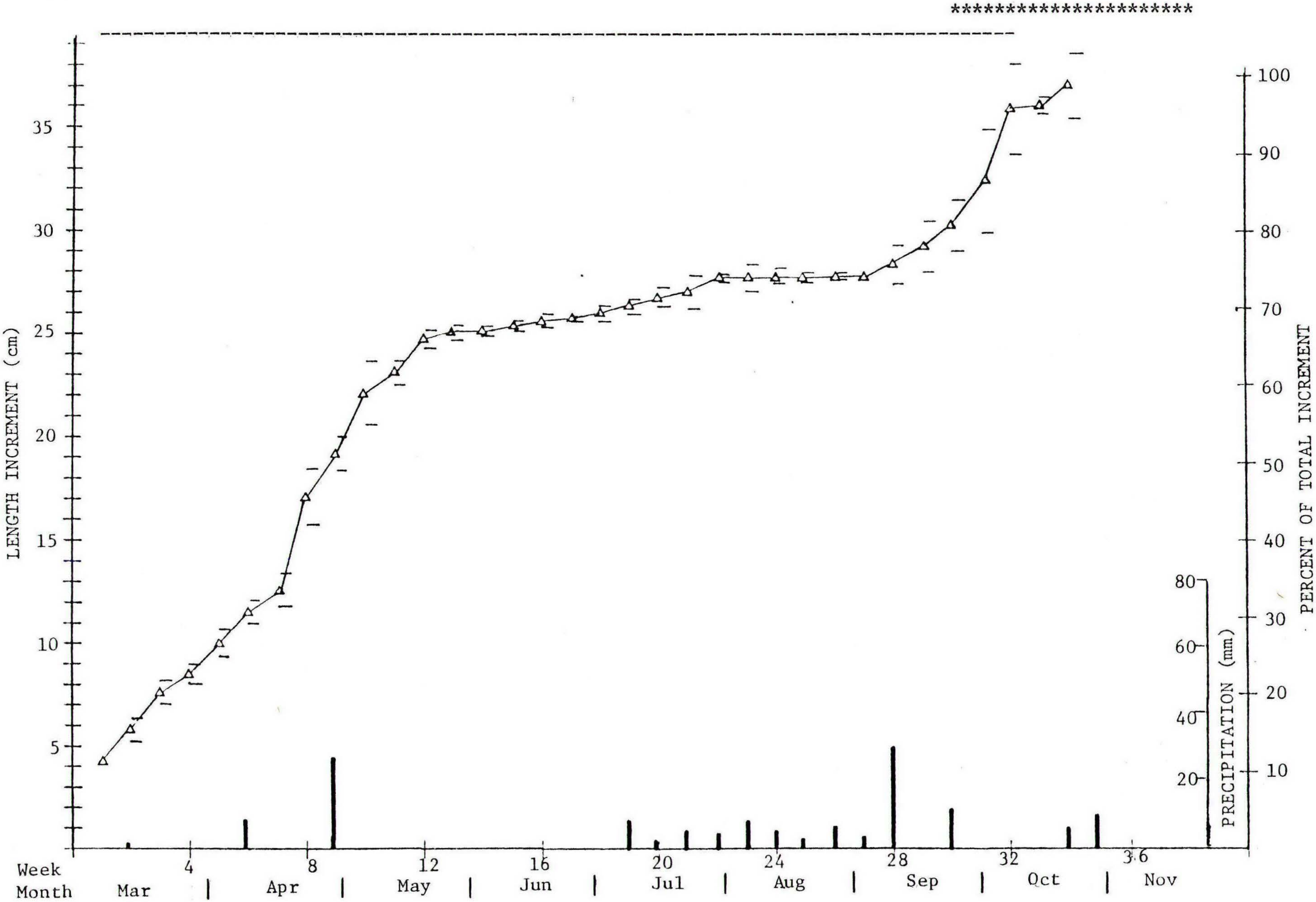

Figure 36. Accumulated weekly length increments for mesa dropseed culms at site A in 1980. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows the period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

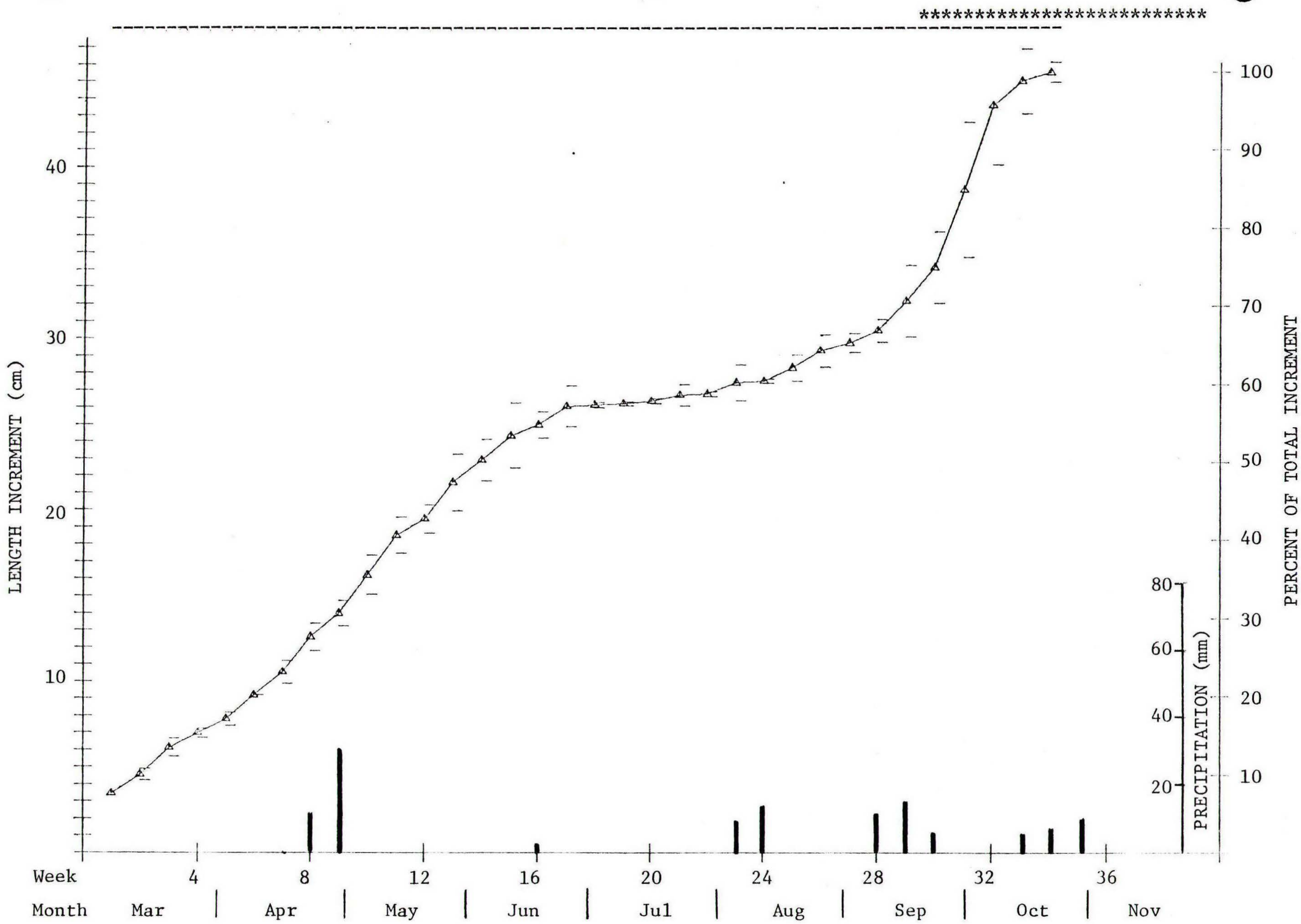

Figure 37. Accumulated weekly length increments for mesa dropseed culms at site B in 1980. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows the period of vegetative growth, the ** line shows the period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

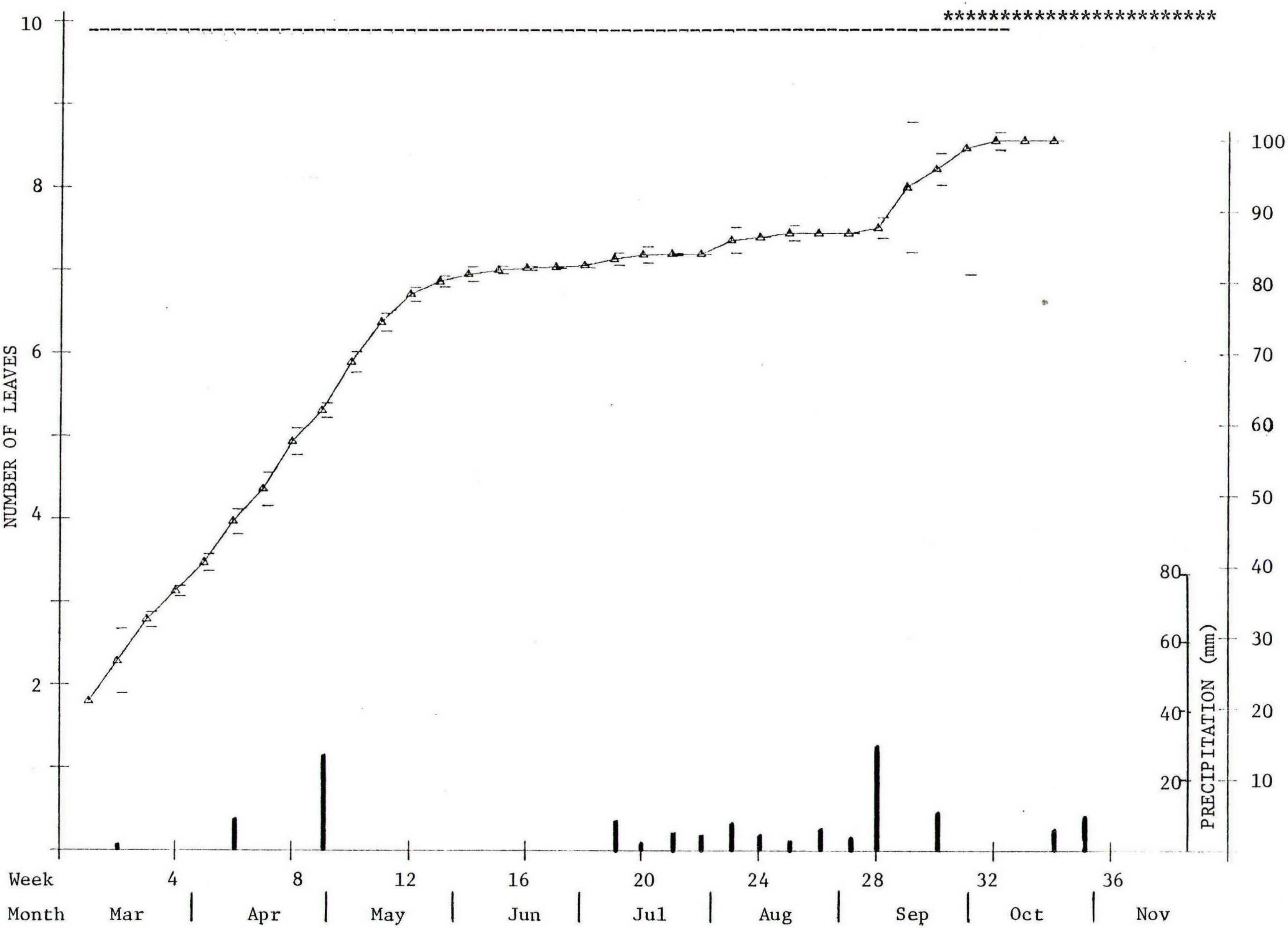

Figure 38. Accumulated weekly leaf increments for mesa dropseed at site A in 1980. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

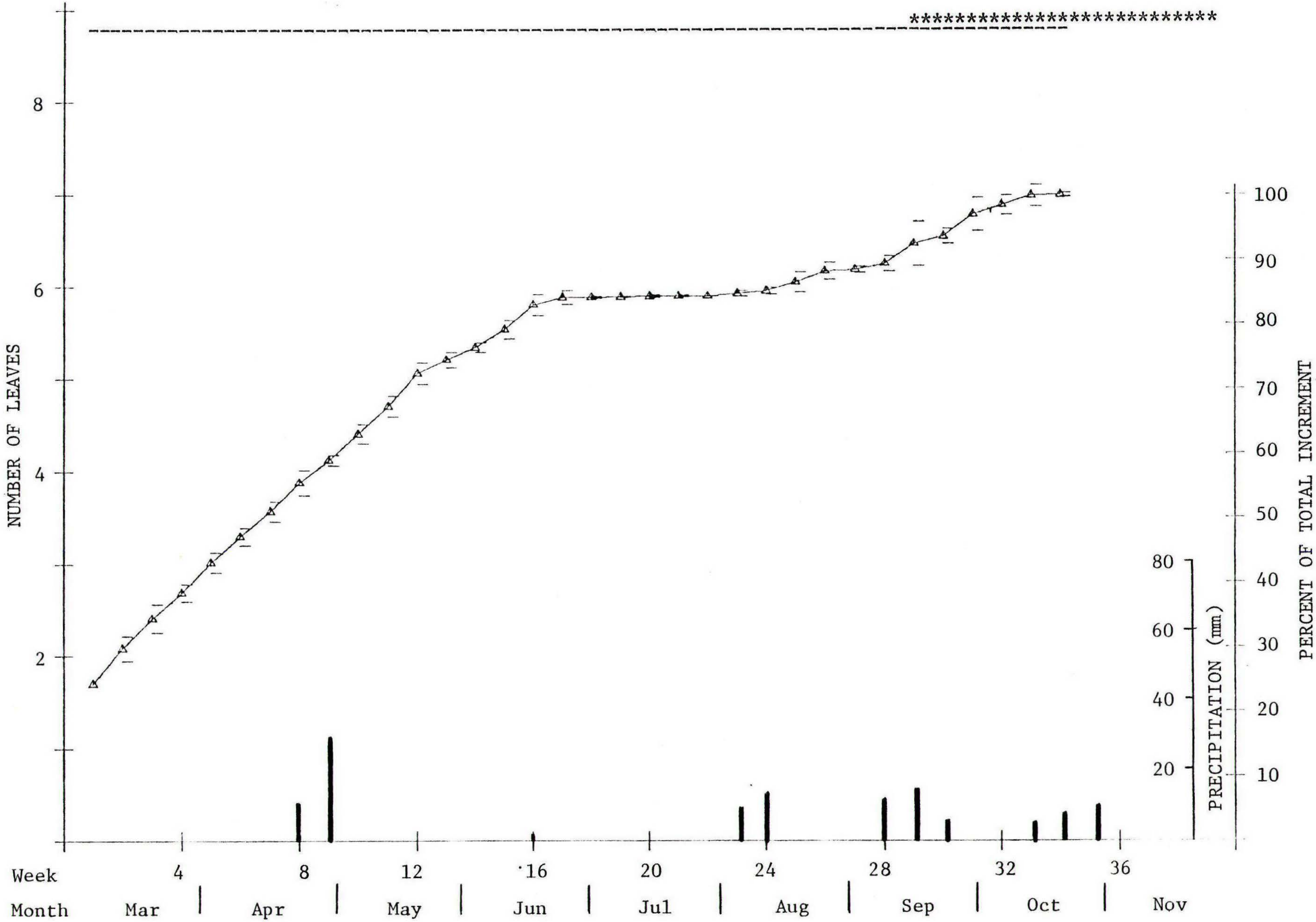

Figure 39. Accumulated weekly leaf increments for mesa dropseed at site B in 1980. The dashes above and below the line denote 95% confidence limits for each weekly increment, not for the accumulated increments. The -- line at the top of the graph shows period of vegetative growth, the ** line shows period of reproductive activity. Weekly precipitation totals greater than 1 mm are shown.

Table XII. Statistics for mesa dropseed plants harvested during 1979 and 1980. Linear regression procedures were used to determine relationships between height, basal area, and volume (basal area x height) as independent variables and weight of plant material as the dependent variable.

Collection date	N	Height of current growth ($\bar{x}$ cm $\pm$ SE)	Basal area ($\bar{x}$ cm^2 $\pm$ SE)	Current growth weight ($\bar{x}$ g $\pm$ SE)	Total weight ($\bar{x}$ g $\pm$ SE
April 27, 1979	20	23.7 $\pm$ 1.07	46.1 $\pm$ 5.89	2.24 $\pm$ .23	22.83 $\pm$ 7.27
September 30, 1979	25	94.3 $\pm$ 2.39	24.1 $\pm$ 3.06	15.83 $\pm$ 2.01	24.14 $\pm$ 3.11
November 13, 1980	25	82.2 $\pm$ 2.57	53.3 $\pm$ 9.61	10.72 $\pm$ 1.61	37.04 $\pm$ 7.20

Coefficients of determination (R^2)

	Current growth weight			Total Weight	
	Height	Basal area	Volume	Basal area	Volume
April 27, 1979	.77	.88	.86	.83	.85
September 30, 1979	.43	.71	.71	.77	.78
November 13,1980	.05	.83	.81	.92	.89

There were some differences in the amount and timing of precipitation events but the total amount received during the growing season was nearly the same; 140 mm at site A and 128 mm at site B. At both sites, the slow rate of culm elongation prevalent during the middle of the season did not accelerate until after precipitation received in week 28.

Inflorescence development did not begin until week 30 and most inflorescences appeared in week 31. Many of the inflorescences were poorly developed. The somewhat limited seed crop had matured by week 38 and all plants were dry and dormant by week 40.

In addition to the rather poor growth resulting from minimal rainfall, the mesa dropseed plants at sites A and B suffered heavy grazing pressure from rodents and insects (primarily grasshoppers) in 1980. For example, to maintain 20 marked, living culms at site B it was necessary to tag 89 culms through the season. Of the 89 culms, 22, or 25%, were lost because they were bitten off by rodents or rabbits. Many other culms died because the leaf blades had been badly damaged by insects.

Collections of mesa dropseed plants were made on April 27 and September 30, 1979 and November 13, 1980. Height of current growth, basal area, weight of current growth and weight of standing dead material were determined for each plant. Table XII presents a summary of the statistics for each collection. Basal area and volume (basal area X height) were about equal in ability to account for variation in weight of current growth and total weight. Height accounted for 77% of the variation in current weight of the April collection date but could account for very little variation in weight at the end-of-season collections. Log_{10} transformations of volume and weight data did not improve R^2 values.

The weight of current growth per cm^2 of basal area at the April,

September and November collections was .049 g, .656 g and .230 g, respectively. Total weight (current growth + standing dead) per cm^2 of basal area was .495 g, .896 g, and .673 g at the April, September and November collection dates, respectively.

On March 20, May 5, June 2, August 6 and November 10, 1980, collections of 100 or more mesa dropseed culms were made. Culm length, number of leaves and weight were determined. Reproductive culms were placed in one class and the vegetative culms were sorted into 4 cm length classes (Table XIII). The average length of the reproductive culm class and the mid-points of the vegetative culm length classes and leaf number were used as independent variables in linear regression analyses with average culm weights as the dependent variable. The coefficients of determination (R^2) for culm weight with height and leaf number were .93 and .84, respectively. The average weight of reproductive culms is separated from the other culm weights with the exception of the few, very long vegetative culms. Thus, mesa dropseed comes close to having distinct phenotypic classes of vegetative and reproductive culm weights.

As with spike dropseed, a test of a culm length based PAF can be made. If the culm growth curve from site A for 1979 is used we find that in week 8 (week of April 27, 1979 plant collection) the 14.8 cm long culms had completed 22% of the 66.9 cm of growth reached at the end of the season. However, the weight of current growth per plant and per cm^2 basal area on April 27 is 21% and 7%, respectively, of the weights determined for mature plants in September. If we are willing to accept the average weight of current growth per plant as statistically adequate we have a good predictive curve for use in deriving a PAF. What happens if we use the culm growth curve for 1979 at site B where growing conditions were less favorable? In week 8 the site B

Table XIII. Average culm weights and average number of leaves per culm for vegetative mesa dropseed culms in 4 cm height classes and a reproductive culm class (infloresence developing or present).

Length Class < cm > cm	N	Number of leaves $\bar{x} \pm$ SE	Weight in grams $\bar{x} \pm$ SE
0 - 4	13	1.1 ± .20	.006 ± .0004
4 - 8	104	1.6 ± .06	.014 ± .0005
8 - 12	64	1.9 ± .07	.025 ± .0017
12 - 16	9	2.7 ± .22	.040 ± .0040
16 - 20	10	2.9 ± .21	.049 ± .0052
20 - 24	16	3.1 ± .18	.076 ± .0056
24 - 28	16	2.9 ± .18	.100 ± .0073
28 - 32	28	3.4 ± .20	.135 ± .0116
32 - 36	31	3.9 ± .20	.195 ± .0143
36 - 40	28	4.3 ± .25	.255 ± .0181
40 - 44	45	4.8 ± .19	.349 ± .0191
44 - 48	49	4.5 + .18	.427 ± .0257
48 - 52	30	4.8 ± .28	.427 ± .0258
52 - 56	23	5.1 ± .30	.527 ± .0302
56 - 60	10	5.6 ± .32	.592 ± .0461
60 - 64	7	6.5 ± .47	.780 ± .0932
64 - 68	1	5.0	.583
72 - 74	2	4.5 ± 2.05	.703 ± .6320
Reproductive class Mean length = 74.1 cm	98	7.2 ± .13	.734 ± .0328

mesa dropseed culms had reached an average length of 14.8 cm or 46% of the 32.2 cm length reached by the end of the season. This illustrates well that variation in growing conditions at local sites must be considered if PAF's are used.

A legitimate question at this point is; are samples of 20 to 50 plants statistically adequate for sampling biomass? The answer is no. Stein's procedure (Steel and Torrie, 1960) was applied to the sample of 50 mesa dropseed plants collected in September, 1979. Considering only the current growth per plant, we would need to sample 1,298 plants if we wanted to estimate the mean current growth per plant within $\pm$ 5% with 95% confidence. Using the yield of current growth per cm^2, it would take only 352 samples to estimate the mean current growth per cm^2 within $\pm$ 5% with 95% confidence. Obviously, when the collection, sorting, drying and weighing of plants and the compilation of data is considered, decisions as to sample size are made on other than statistical criteria.

On May 4, 1979 a fairly uniform stand of mesa dropseed at site B was selected. Four adjacent plots, 2 m x 30 m were laid out. Two clipping procedures, clipped at ground level and clipped at a height of 10 cm and a non-clipped control were applied to randomly selected plots. Starting at one end of the plots all mesa dropseed plants encountered were marked with numbered stakes and the appropriate treatment applied until 100 plants had been included in each treatment. Periodic observations were made during the season and on November 11, 1979 the plants were clipped at ground level and the amount of current growth determined for each individual plant. Average height of the current growth when the treatments were applied was 22 cm.

The total season's production of current growth (green material removed at May 4 added to material produced during rest of season) averaged 2.04 g,

4.11 g, and 4.11 g per plant for the ground level clip, 10-cm clip, and non-clipped treatments, respectively. The current growth present at the end of the season averaged 0.86 g and 3.52 g per plant for the ground-level clip and 10-cm clip, respectively.

At the end of the season the heights of the unclipped, 10-cm clip and ground-level clip were 50 cm, 49 cm, and 20 cm, respectively. The 10-cm clip did not have any apparent effect upon timing or degree of phenological development. The average number of infloresences produced per plant was 3.3 and 3.0 for the 10-0m clip and non-clipped treatment, respectively. On the plants clipped at ground level there were only .36 infloresences per plant and on November 11, 50% of the inflorescences were still in the boot stage. On the other two treatments inflorescences were all mature, or nearly so, on November 11. Sixteen of the 100 plants in the ground-level clipping treatment died during the season while no plants died in the other two treatments. It would appear that relatively light clipping (grazing) does not have an effect on phenological timing or degree of expression but heavy rates of herbage removal, even early in the season can not only delay, but affect the degree of phenological development.

Since data from plants harvested early in the season and at the end of the season are provided by the clipping experiment another weight-based test of a culm growth curve as a PAF index may be made. Using the culm growth curve of mesa dropseed from site B for 1979 (Fig. 34) we find that on May 4 (week 9) the culms had achieved 57% of their total length growth for the season. On May 4 an average of 1.06 g per plant was harvested on the ground-level clipping treatment; this is 26% of the average weight per plant at the end of the season on the other treatments. The site A culm growth curve for 1979 (Fig. 32) gives more realistic results. On May 4 the culms had achieved 29% of their total growth which is not far from the 26% determined from the clipping experiment.

The Microenvironment and Phenological Events

Intuitively we know that plants will respond to their immediately surrounding physical environment. While an in-depth analysis of environmental measurements obtained in this study is not possible at this time, a few examples of microenvironmental differences which influence plant phenology will be presented.

The mesquite sanddune topography of study sites A and B could be expected to show the most variation in microenvironment. A good example is the temperature of the soil on the cardinal exposures of a mesquite dune. In Fig. 40, a 24 hour time span showing the soil temperature at a depth of 5 cm is presented for Julian day 59, 1980 (February 28). At this time the mesquite branches had no leaves. There is a very distinct separation of soil temperatures on the cardinal exposures of the dune throughout the day. The maximum temperature difference between two exposures occurred at 1700 hrs when the west exposure temperature exceeded that of the north exposure by 12.5° C Throughout the 24 hour period the south exposure was at least 6° C warmer than the north exposure. Temperature differentials such as these explain why annuals are more advanced in growth on south-facing dune slopes than they are on north slopes in early spring. It is also the reason why the first mesquite buds often open 1 to 2 weeks earlier on the south side of a dune than they do on the north side. The temperature differential among dune exposures decreases as the season advances and the sun angle becomes less acute but persists to some extent throughout the season.

The air temperatures taken at heights of 1.3 and .5 m reveal that the lower level is warmer than the upper level. On February 28 the average hourly air temperature at .5 m exceeded that at 1.2 m at 1400 hrs and remained 0.9° C higher than the 1.2 m air temperature for 4 hrs. This, of course, is a

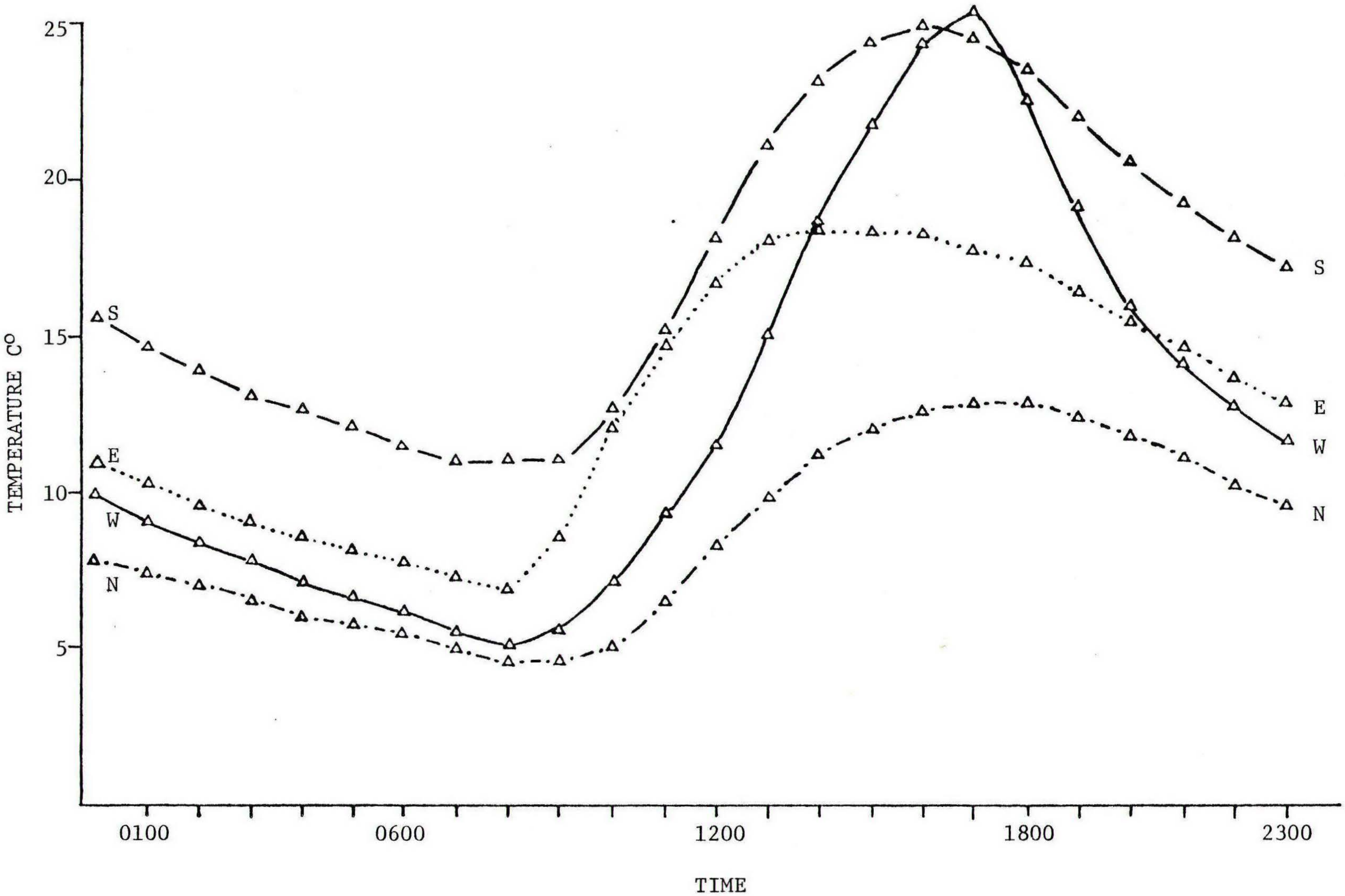

Figure 40. Soil temperatures at a depth of 5 cm on the north, west, south, and east exposures of a mesquite dune on February 28, 1980.

relatively small difference in temperature but can have an influence on plant growth in early spring. Later in the season the temperature difference is typically greater and lasts longer. For example, on April 18 the 0.2 m air temperature exceeded that at 1.3 m from 0900 hrs to 1800 hrs with a maximum differential of 3.6° C.

All of the microenvironmental differences produce their most noticeable effects on plant phenology early in the spring. Later in the season the microenvironmental differences probably influence plant growth less directly, although an effect on soil water supplies, and hence plant development, is probably being exerted.

A question basic to plant phenology investigations is how useful are measures of the physical environment obtained from official weather stations. Returning to the day of February 28, 1980 we find at the plant environment level (.2 m) a maximum hourly average temperature of 29.6° C and a minimum temperature of -1.4° C. (Note: temperature averaged over an hour may or may not express the true maximum and minimum temperatures as recorded on a mercury thermometer). At the Universty weather station in Las Cruces the maximum and minimum temperatures for February 28 were 24.4° C and 1.7° C., in other words, not so hot and not so cold. At the Jornada Headquarters weather station the maximum and minimum temperatures recorded were 22.8° C and -3.9° C, respectively, not so hot but colder and in general a better match for the temperatures at the study site. Data from weather stations far removed from study sites must be extrapolated with care if the interest is in specific microsites. In general, weather station records are useful in terms of general climate patterns which will largely dominate the expression of vegetation phenophases.

Phenological Adjustment Factors

The phrase "phenological adjustment factor" is somewhat misleading in view of the way it is to be used, i.e., upward adjustment of biomass determinations made at a point in time prior to the development of the peak standing crop of the species. Use of the word "phenological" seems to imply that as a plant progresses through vegetative and reproductive phenophases there is an accompanying increase in biomass. Generally, this is true but there is no fixed constant for a given species.

The proportion of mature biomass contributed by any plant part, leaves, clums, inflorescences, seed, etc., can vary widely and is a reflection of the conditions under which the plant developed. Nadabo (1978) found broom snakeweed flower parts to contribute 5% of total biomass in two populations while during the same year in another population flower parts contributed 13% of the total biomass. Annual herbs were found to exhibit greater vegetative fractions (i.e. smaller reproductive fractions) during rainy years than they did in dry years (Jaksic and Montegnegro, 1979). Vegetative growth and reproductive behavior of winter annuals in the Mojave and Great Basin deserts were found to be highly variable from site to site and from plant to plant on the same site (Beatly, 1969). Cunningham, et al. (1979) found that biomass allocated to reproduction in creosotebush (Larrea tridentata) depended upon timing and extent of soil moisture availability. A "phenological" adjustment would appear to be most applicable in deciduous shrubs or trees where the presence or absence of leaves is a have or have not situation and the percentage increase in biomass when leaves develop will have some more or less constant relationship to the biomass of the perennial stems.

It seems that a "biomass adjustment factor" would be a more descriptive and less misleading phrase. Irrespective of what the adjustment factor is

called, it is very difficult to derive. The first problem is to find some recognizable or measureable parameter of the plant which can be scaled in some manner to biomass increase through the season. As has been shown in the discussion of individual species there are few easily determined parameters which give a good index to plant biomass. Culm length in grasses appears to have some potential but its use would mean the determination of the average length of culms per plant or per unit of basal area, a very laborious process. Clipping an adequate sample of plants for direct biomass determinations at weekly or bi-weekly intervals during the season is judged to be a prohibitatively expensive procedure.

Perhaps the biggest obstacle to the use of a biomass adjustment factor is the variability in biomass production between seasons. This is illustrated well by blue grama (Bouteloua gracilis) production data collected by Turner and Klipple (1952). As can be seen in Fig. 41, an adjustment factor could be derived for the March to June period which would apply to more than one year. After June the grasses are responding to seasonal rainfall and there is no single adjustment curve which will apply to both the wet and the dry years. A whole family of curves would be required to fit all possible outcomes of peak standing crop biomass production between 550 and 1400 pounds per acre. Even if one had the necessary curves there is no way of knowing which one to apply until the season is over.

All of the measurements made in this study indicate that the biomass accumulation of grasses and forbs is directly dependent upon summer rainfall. The rainfall inputs dictate not only the timing but also the magnitude of biomass increases. This means that any biomass adjustment factor must be specific for a season or, perish the thought, be adjusted by a "rainfall input factor".

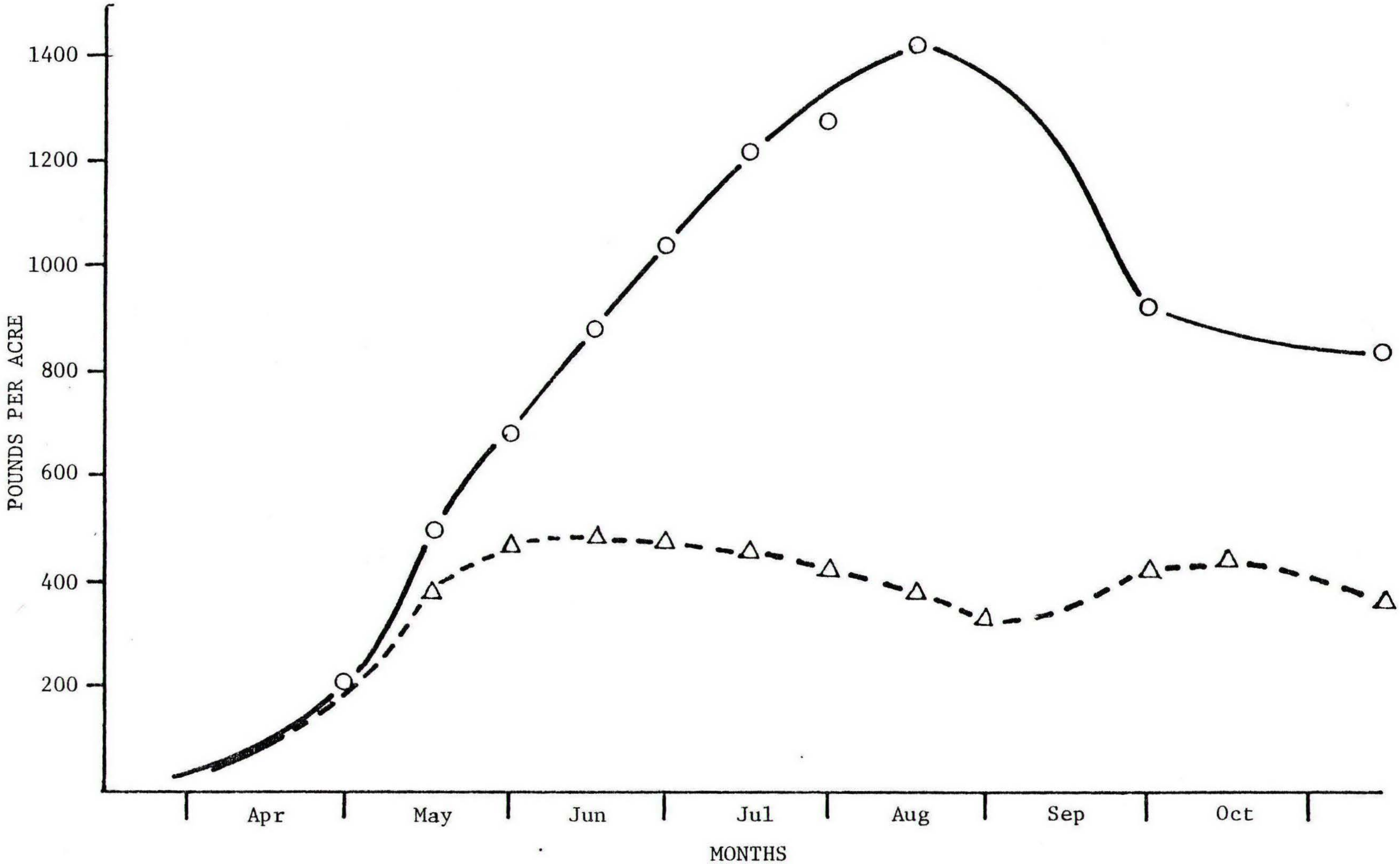

Figure 41. Above ground biomass production of blue grama in a wet season (solid line) and a relatively dry season (dashed line). Based on data presented by Turner and Klipple (1952).

Conclusions

The annual plants examined in this study function primarily as winter annuals. High populations are reached in those years with above average fall and winter precipitation. The life cycle of the annuals is relatively brief but can be prolonged by summer precipitation. Typically, the reproductive phenophase starts early in the season and proceeds concurrently with vegetative growth. Two distinct reproductive cycles, as evidenced by Wislizenus spectaclepod, may occur. There is the potential for a tremendous range in size of mature annuals. This range in size is often present in a given population and is certain to be expressed in the population means among years. In favorable years annual plants can make substantial contributions to total biomass production. One aspect of annual species biomass dynamics not addressed in this study but very important when considering adjustment factors is the biomass loss as the annual plant populations are thinned through competition. Perennial forbs, while maintaining more stable populations respond to summer rainfall much as do the annuals.

The shrubs examined, fourwing saltbush and honey mesquite, are more stable in phenophase expression than are the herbaceous plants. However, twig growth does respond to summer rainfall. Dimensional analyses offer some hope for biomass estimation for the shrubs but much more testing needs to be done. While it may be possible to estimate total biomass of the shrubs, the measurement of the annual woody increment will always be difficult.

Broom snakeweed seems to follow a set pattern in the initiation of the reproductive phenophase. Vegetative growth during the season was closely correlated with rainfall. Dimensional analyses by Ludwig, Reynolds and Whitson (1975) and in this study gave good predictions for total biomass of broom snake-weed. It must be emphasized that in this study only totally live plants

were examined. Broom snake-weed populations frequently contain a high proportion of partially decadent plants. In a study involving 200 broom snakeweed plants, a volumetric measure which would explain a high percentage of the variation in weight was not found (Nadabo, 1978).

The phenology of the perennial grasses is largely determined by the timing and amount of summer rainfall. This was very evident from the difference in dates of inflorescence production in 1977 and 1978. Not only the timing but the magnitude of phenophase expression is determined by precipitation. Tobosa consistently displayed two distinct reproductive phenophases. The relationships shown between culm length and culm weight in the grasses are deserving of further study. The high correlation between length and weight does not, by itself, offer the means for deriving a practical method of adjusting biomass measurements.

The foliage removal experiments indicated that grazing could affect both the timing and magnitude of the reproductive phenophase in mesa dropseed and black grama. The effect of foliage removal needs more study because other investigations have failed to find an effect of grazing upon phenological timing (Dickinson and Dodd, 1976).

The various measures of plant growth have been shown in the form of growth curves. This was done so that they could serve as adjustment curves for point-in-time samples. However, the trials conducted using actual plant biomass samples amply illustrate the inadequacies of adjustments based upon the curves. It is recommended that the growth curves not be used for biomass adjustments. All of the evidence assembled indicates that no biomass (phenological) adjustment factor can be derived for a given species that would apply to more than the range site and year upon which it was based.

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